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GEOLOGICAL SURVEY

Seasonal biological observations near the ocean bottom on the southern side of Georges Bank: December 1976 - September 1977

By

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ABSTRACT

Seasonal differences in fish and mobile benthic invertebrates were examined from photographs taken every 3-4 hours from an instrumented tripod maintained on the seafloor on the southern side of Georges Bank (lat 40°51.4′N., long 67024.1-W.) from December 1976 to September 1977. In winter, the ocean bottom was disturbed mainly by currents and surface waves associated with storms. Sediment resuspension, ripple formation, and scour were common. In spring and summer, however, the ocean bottom was disturbed primarily by the biological community. Fish, crab, polychaete, and molluskan tracks and burrows contributed to distinct biorelief. Seasonal variations in the abundance and species of fish were correlated with temperature and fluctuations in temperature associated with the cross-shelf movement of the shelf-water/slope water front in winter, and with advection and/or downwelling of warm waters in summer. Benthic invertebrates were most active in early winter, spring, and summer when water temperatures exceeded 6°C. This seasonal benthic activity probably affects the extent of mixing and erodibility of the surface sediments.

INTRODUCTION

Studies designed to determine the regional geology of the U.S. Atlantic Outer Continental Shelf (OCS) and to assess potential oceanographic and geologic hazards associated with offshore drilling have been conducted by the United States Geological Survey (USGS) in cooperation with the Bureau of Land Management (BLM) since 1975 (Aaron, 1980a, 1980b; O'Leary, 1982; McGregor, 1983). A major component of these studies was an extensive" field program to determine the frequency, direction and rate of sediment movement, the processes causing movement, and the spatial and temporal variability of movement on the continental shelf (Butman and Folger, 1979; Aaron and others, 1980; Butman, 1982; Butman and Moody, 1983). As part of this study,long-term monitoring stations were maintained almost continuously for several years at several locations on the continental shelf in the North and Middle Atlantic BLM OCS planning areas. At these long-term stations, bottom tripods which measured temperature, current, light transmission, and pressure, and which photographed the seafloor every few hours were maintained to document the physical processes of bottom sediment movement (Butman and Folger, 1979).

The bottom photographs provided a continuous time-series of the ocean bottom microtopography and the benthic biology. It was apparent that these observations provided a unique opportunity to examine *in situ* changes in benthic biology as well as sediment movment. In particular, the temporal variability of the demersal nekton within 2 m of the seafloor and of the mobile epibenthic invertebrates located on the seafloor could be observed. In addition, the presence and activity of the macrofauna located in the upper few centimeters of the surficial sediments could be partially determined. Moreover, the photographs clearly suggested that the benthic community affected the erodibility of the surficial sediments. This paper presents an analysis of the bottom photographs obtained from December 1976 to September 1977 at one long-term station.

Station A, located on the southern flank of Georges Bank in water 85 m deep (fig. 1) was selected for this biological study for several reasons. Station A was near the mean position of the shelf-water/slope-water front, the boundary between shelf water and slope water (McLellan and others, 1953; Beardsley and Flagg, 1976; and Wright, 1976). Here, meanders and intrusions of the front locally cause variability in temperature and salinity, especially in late summer, fall, and early winter (Flagg and others, 1982; Butman and

Beardsley, 198_). These variations in water temperature associated with the proximity of the shelf-water/slope-water front, and the large seasonal change in temperature make Station A appropriate for a study of benthic populations in relation to water temperature and water masses. The variability of currents and temperature at Station A are described in detail in Butman and Beardsley (198_).

Station A was also selected for this biological study because of the ocean bottom sediment type, the important commercial fisheries, and the location near current petroleum exploration. The southern flank of Georges Bank is covered by a late Pleistocene surficial sand sheet; the surficial sediments are reworked and resuspended by winter storms and tidal currents (Knebel, 1981; Butman, 1982; Butman and Moody, 1983). The sediments are largely sand (90%) and contain a small amount (<8%) of silt plus clay (Bothner and others, 1979). The surface sediment grain size is predominantly between 2 (0.25 mm) and 4 (0.063 mm) phi. Important commercial shellfish populations, such as ocean quahogs which are known to inhabit sandy detrital environments, occur along the southern flank of Georges Bank (Merril and Ropes, 1969). The southern flank of Georges Bank is also a prime commercial finfish area. It is located within subarea 5 (5ze, specifically) and statistical area 6 of the International Commission for the Northwest Atlantic Fisheries (ICNAF). In 1973, the reported landings for finfish and squid from ICNAF subareas 5 and 6 exceeded 3.0 metric tons/km^2 with red hake and cod as the two important demersal species harvested (Hennemuth, 1975). Station A is also near important spawning grounds for these two finfish and other commercially important species (Colton and Temple, 1961; Olsen and Saila, 1976; Hare, 1977; Colton, 1979; King, 1980). Finally, station A is located within tracts leased in Sale 42 for oil and gas exploration, and In the region offered as part of

Sale 52 (Aaron, 1980a; Aaron, 1980b; Aaron and others, 1980a; Carpenter and others, 1982; O'Leary, 1982). An understanding of seasonal changes in the benthic populations and of sediment movement is important to assess possible environmental consequences of oil and gas exploration.

The original objective of this study was to use the bottom photographs to simply characterize the ocean bottom microtopography, and to illustrate the changes in the ocean bottom caused by storms, currents and bottom organisms over a nearly continuous ten month period at one long-term station (Bryden and Butman, 1981). However, the simultaneous measurements of temperature, turbidity (measured via light transmission), current, pressure, and storms documented some of the physical factors which might partially determine seasonal changes in abundance, diversity, distribution, and activity of the nekton and benthic fauna. For example, investigators have long believed that temperature is one of the most important factors which determines the distribution of groundfish, but field data which documents this role has been difficult to obtain (Edwards, 1964). In this paper, the seasonal changes in abundance and diversity of nekton and benthic invertebrates is described based on the photographs. In addition, the influence of water temperature and position of the hydrographic fronts on the observed patterns of abundance and diversity of benthic populations is investigated. It was beyond the scope of this paper to separate the influence of temperature and temperature fluctuations which are interrelated.

A final objective is to qualitatively document the influence of the benthic community on the erodibility of the surficial sediments. The benthic biological community may alter the physical bottom roughness, and may bind, rework, loosen, repackage, or otherwise change the bottom stress required to erode the surficial sediments. Temperature also apparently affects sediment erodibility but the effect is subtle in that it alters the activity of the benthic organisms and micro-organisms which may bind (or rework) the sediments. The influence of biological activity on the entrainment of marine sediments is a complex problem which has recently been recognized and present research is being conducted both in laboratory flumes and in the field (Fager, 1964; Postma, 1967; Rhoads and Young, 1970; Rhoads and others, 1978a; Yingst and Rhoads, 1978; Ekman and others, 1981; Jumars and others, 1981; Newell and others, 1981; Grant and others, 1982; Rhoads and Boyer, 1982).

Finally, this analysis is a pilot effort to assess the usefulness of long-term biological observations made from the time series bottom photographs. Discharge of drill muds and cuttings by OCS drilling may slightly alter the bottom sediments and the erodibility of the sediments; temporal changes in the sediment characteristics may effect ground fish food supplies by altering the benthic community and spawning by altering the distribution of larval settlement. An understanding of the natural relationship between the benthic community and sediment movement is required to assess these effects. The bottom tripod system may be one method to provide long-term simultaneous information on sediment movement and the benthos, and their relation to the demersal nekton.

FIELD PROGRAM

Bottom tripod moorings were maintained on the southern side of Georges Bank (lat. 40051.4-N., long. 67°24.1´W.), Station A (fig. 1), from December 1976 to September 1977. Three successive deployments of the instrument systems were made during this period: (1) December 5, 1976 - March 18, 1977 (winter); (2) April 16, 1977 - July 8, 1977 (spring]; (3) July 9, 1977 - September 19, 1977 (summer). The USGS mooring identification numbers for these three deployments are 120, 126 and 132, respectively.

The bottom tripod system was designed for long-term sediment transport studies on the Continental Shelf and consists of sensors for current, pressure, temperature, light transmission, and bottom photography; a data recording unit; and a tripod frame on which the above are mounted (Butman and Folger, 1979). Bottom photographs were obtained by means of a deep-sea Benthos camera (35 mm) having a 750-frame capacity. Mounted approximately 2 meters above the sea floor, the camera provided a viewing area about 2 m x 1.5 m. An antifouling porous bronze ring impregnated with a tryalkyltin compound was used to inhibit biological growth on the camera lens.

A series of hydrographic sections were made across the southern flank of Georges Bank from about the 60-m to the 200-m depth contours passing through Station A. One section was made in October, 1976 prior to the data presented here. The four remaining sections were made during the successive tripod deployment and recovery cruises in December, 1976 and April, July, and September, 1977.

DATA ANALYSIS

The bottom tripod system measured average temperature, light transmission, and pressure every 7.5 minutes (winter and spring), or every 3.75 minutes (summer). In addition, pressure and current were burst sampled every 3.75 or 7.5 minutes (12 samples spaced 4 s apart). The burst current measurements were vector-averaged, and the standard deviation of the burst pressure measurements (PSDEV) was computed for each sampling interval. PSDEV is a measure of the high-frequency bottom pressure fluctuations associated with surface waves. The light transmission observations were normalized by the maximum sensor output during the deployment and thus is only a relative measurement of the amount of material in suspension. All physical time-series data presented in this paper are hour-averages of the original data series. The average temperature and the standard deviation of temperature was computed every 15 days and monthly at the 75 m and 85 m depths for comparison with the biological observations.

The black and white photographs were printed first at 11"x14" for analysis. The horizontal scale of the photographs was computed from the height of the camera above the bottom and the camera viewing angle. All measurements in length were made in centimeters and are accuarate within ±1 cm. Photographs used for illustration in the text are identified by day, month, and hour (EST) in the upper left and USGS mooring record number in the lower right. The appropriate horizontal scale is also shown in the lower right corner.

Each photograph was examined for ripples, scour, sediment resuspension, bottom microtopography and changes in microtopography. The number of fish and benthic invertebrates in each photograph was counted, and the length of important commercial finfish species was measured. These fish had to be located fully in the viewing area and on or near the ocean bottom in order to accurately determine length. Age and growth data compiled by Bigelow and Schroeder (1953) and Musick (1974) was used with our length data to estimate the age of all positively identified individuals. Positive identification of nekton and benthos was not always possible. Unidentified individuals, either fully or partially observed in the viewing area were included in a separate category.

In counting the nekton and benthic organisms, each photograph was treated as a new observation; no attempt was made to identify "repeat" individuals in succeeding photographs. The authors recognize that any Individuals which remain in the field of view for long periods of time will increase the number of individuals observed. Consequently, the absolute numbers of fish observed are probably not significant and cannot be directly related to the actual density of individuals on the seafloor. These absolute numbers are not considered of primary importance in this biological study. Analysis will concentrate on the trends of abundance and species with time.

Photos were taken every 4 hours during the winter and spring deployments, and every 3 hours during the summer deployment. This difference in sampling interval was introduced by differences in deployment periods and limitations in the camera-s film capacity. The fish and benthic invertebrates are tabulated and plotted as observations per day which depends on the picture sampling rate. When monthly statistics are compared, the numbers are normalized to a sampling rate of 6 pictures per day. This normalization procedure requires a 75 percent reduction in the summer data. No data was collected March 19 through April 16, 1977, and the observations terminated on September 18, 1977. For these incomplete months, the fish and benthic invertebrate statistics were extrapolated to a full month of observation. Other shortened months were likewise appropriately adjusted to make all data comparable.

We recognize the tripod mounted instrument system may be a haven for nekton and mobile benthos and thus the biological observations may not be entirely representative of the surrounding area. The density of fish and invertebrates has been observed to increase around piles of drill cuttings and debris on the seafloor at exploratory well sites and offshore oil platforms (Wolfson and others, 1979; Gilmor and others, 1981). Detailed comparisons of the tripod observations with simultaneous trawl data, submersible observations, or regional camera surveys, and possibly between observations of arrays of tripods are required to assess the quantitative accuracy of these unique observations. Analysis in this paper is concerned primarily with the seasonal trends and changes in the abundance and predominance of the nekton and benthos which are probably less affected by the tripod system. The immobile benthos were probably not affected by the tripod system. Where possible, the observations are related to other seasonal studies.

RESULTS

The hydrographic sections are presented first to describe the temperature field across the southern flank of Georges Bank dominant for each season. The time-series measurements of temperature, light transmission, pressure, and current are next discussed to provide an understanding of the changing environmental conditions in the immediate location. Biological observations of nekton and mobile (epi)benthic invertebrates are presented in tabular format by selected time intervals to best show changes in abundance and species as a function of temperature. Monthly totals of these observed individuals complete this data presentation. These biological observations are displayed graphically together with the physical time-series data for each season.

Hydrographic Sections

In this analysis, water temperature and temperature variability are used as indicators of the tripod location with respect to various shelf fronts. The thermal structure on the southern flank of the bank is complex and varies seasonally (figs. 2A, B, C). Throughout the year, the water column in depths less than 60 m was vertically well mixed by the tidal currents, and in winter, it was generally well mixed across the southern flank of Georges Bank to the shelf break. At the shelf break, the shelf-water/slope-water front separated cooler, fresher shelf water from warmer, saltier slope water. From late winter until early summer, increases in temperature at Station A may be interpreted as intrusions of warm slope water onto the shelf (fig. 2A). In early summer, the water on the crest of the bank has warmed and remained vertically well mixed (fig. 2B). In contrast, in water depths greater than 60 m, a seasonal thermocline has developed. A nearly vertical front at 60-m isobath separated isothermal bank water from warmer water offshore at the surface and from cooler water offshore at depth. A near-bottom band of cooler water occurred between the top of the bank and the shelf-water/slope water front. During this period, temperature increases at Station A were ambiguous and may be interpreted as on-shelf intrusions of warm water, off-shelf movement of bank water, or downward movement of the seasonal thermocline. The July 1977 OCEANUS-29 section (fig. 2B) shows the core of cooler water to be offshore of Station A, which suggests that warmer water may have to come from the crest of the bank. The September 1977 ADVANCE-II section (fig. 2C) shows a complex thermal structure; a warm midwater intrusion separates the cold band into two ribbons. Here, water warmer than 14°C near bottom at Station A might have come from downwelling.

Winter: Record 120 (December 6, 1976-March 18, 1977)

Physical observations

During the winter months from December to mid-February, numerous storms, indicated by increases in pressure standard deviation (PSDEV), were observed at Station A (December 8, 13, 21, 22, 27, 30, 31; January 5, 8, 11, 15, 27, 29; and February 6, 20) (fig. 3). These storms, which were most intense on December 8, 13, 22, 27, and January 8 and 11, were accompanied by large surface waves which caused near-bottom sediment resuspension and ripple formation. The ripples were mostly fragmented asymmetric ripples 4-16 cm wide (crest to crest). On January 11, when PSDEV levels exceeded 25, symmetric ripples 9-16 cm wide (crest to crest) were observed which increased in wave length as PSDEV values Increased (fig. 4). After the storms, the ripples degraded.

Through December and early January, resuspension of the surficial sediments and moderate to extensive (75-90 percent) detrital cover occurred during storm events. From December 25, 1976 to January 3, 1977, frequent storms and rapid temperature changes were associated with the movement of the shelf-water/slope-water front (fig. 3) and probably contributed to the deterioration of the detrital cover. Following the January 5 storm, most of the detrital cover, henceforth identified as a biological "mat," was removed. Thereafter, storms and tidal currents were sufficient to rework the unbound surficial sediments. From mid-February through March, asymmetric ripples 15-20 cm wide (crest to crest) that oscillated with the semidiurnal tidal currents were continuously observed. Shell debris accumulated within the ripple troughs (fig. 4).

The temperature and transmission observations (fig. 3) suggest that the December-March period can be divided into four periods: (1) December 6-24, (2) December 25-January 2, (3) January 3-February 4, (4) February 5-March 17. For the most part, from December 7 to 24, warm (>10*C), relatively clear water occupied the mooring location. Brief interruptions in these physical conditions were associated with storms apparent on December 8, 13, and 21-22. The hydrographic section made on December 4-5 suggests that the warmer water (>13°C) was an intrusion of near-bottom slope water (fig. 2A). From December 25 to January 3, the water at Station A cooled from 10°C to

$6^{o}C$. Two major intrusions were observed: on December 25, cooler, more turbid shelf water was observed (the water temperature dropped from $10^{o}C$ to $7^{o}C$); and during January 1-2, warmer, clearer slope water occupied the mooring site (the water temperature increased from approximately 7°C to $11^{o}C$). These major intrusions and 1^{o}-$2^{o}C$ variability at the semidiurnal tidal period indicate that the shelf-slope/slope-water front was located within a tidal excursion (5 km) of Station A during this period. After January 3, the water cooled more slowly and reached a winter minimum of less than $4^{o}C$ in early February. The reduced semidiurnal variation in water temperature during January and February indicates that the shelf-water/slope-water front was located offshore of Station A by at least a tidal excursion (about 5 km), except from January 20-24, and that Station A was located within the cold shelf water. The water gradually warmed from the winter minimum (on February 4) by approximately $0.15^{o}C$/day until the end of the observation period.

Throughout the winter observation period, the semidiurnal tide dominated the current and pressure measurements and there was a spring-neap variation in amplitude. During the neap tides, maximum bottom-current speeds were typically 25-30 cm/s, whereas during the spring tides, maximum bottom speeds were typically 30-40 cm/s. Bottom scour was observed when current speeds exceeded approximately 30 cm/s.

Biological observations

Nekton

Because the temperature measurements suggested discrete periods in which to look at the biological data, the nekton and invertebrates were tabulated and analyzed in a similar manner (table 1). Most fish were observed during December when the water temperature exceeded 6°C; their number decreased in

January, February, and March when the water temperature was lower (fig. 3). Fish were most diverse in December when hake and cod were predominant (table 1).

From December 6 to 24, when warm slope water was present, eight species of fish were observed (table 1). These positively identified fish, together with those of the unidentified species, averaged 2.8 observations per day. The most frequently observed fish were red and/or white hake Urophycis spp. (fig. 5). The hake averaged 11.1 inches in length and were between one and two years old. Other fish were markedly less frequent (table 1, figs. 6 and 7). The only other nekton observed at this time or any other time during this biological study was the squid Loligo pealii which appeared just prior to the first shelf water intrusion on December 23-24 (fig. 8A).

Between December 25 and January 2, when the shelf-water/slope-water front was near Station A (fig. 3), six species of fish were observed (table 1). These, together with the unidentified species, averaged 3.4 fish observations per day. The most frequently observed fish in this period were young cod Gadus callarisa (fig. 8B). These fish averaged 13.6 inches in length and were nearly 2 years old. This change in species dominance from hake to cod suggests a temperature preference which is discussed later. The next most frequently observed fish was sculpin, most likely longhorn Myxocephalus octodecimspinosus (table 1).

From January 3 through February 4, when the water was colder than 6°C and at its winter minimum (4°C), less than 0.5 fish per day were observed; sculpin was the most frequently observed (fig. 3, table 1). From February 5 through March 17, as the water gradually warmed, fish observations nearly doubled (table 1). Cod, which were predominantly young 3-year-olds averaging 18.8 inches in length were most frequently observed (table 1; fig. 9A). The other fish identified were haddock Melanogrammus aeglefinus and sculpin (table 1).

Benthos

When water temperatures were warmer than 10°C prior to December 25, mobile benthic invertebrates were active and presumably occupied with food foraging. Representatives of several diverse feeding strategies were common: burrowers (mollusks and polychaetes), scavengers (crabs and whelks), carnivores (starfish), and browsers (gastropod and sand dollars) (table 2). Of these, starfish (1 to 5 per photo) were the most common mobile epibenthic invertebrates observed (table 2; figs. 5, 6, and 7). Paired siphon holes (incurrent and excurrent valves), burrowing depressions similar to clam beds, empty bivalve shells (mostly ocean quahogs), and a detrital cover all suggested the presence of an active molluskan community dominated by the ocean quahog (Arctics islandica) (fig. 9). Singular holes with associated fecal mounds were also obvious and are attributed to polychaetes, sipunculids, and tubeworms. Surface grab samples taken at this location confirm-these infauna macrobenthic invertebrate populations as well as the presence of a significant meiofauna amphipod population, Ampelisca spp.

During this warm period, a moderate to extensive biological "'mat'* covered 75-90 percent of the field of view and dominated the ocean bottom microtopography (figs. 5, 6, 7, 8, and 9). This mat, which seemingly bound the upper surficial sediments, appeared to be composed of a gross benthic assemblage of suspension-feeding mollusks, tube-dwelling polychaetes, and tube-dwelling amphipods (F. Grassle, pers. commun., 1981). Microorganisms, associated with the detrital/fecal matter contributed by the larger benthic invertebrates, were presumed important elements in this mat. Disturbances in this mat were predominantly biologically induced. Pits and tracks created by benthic invertebrates and fish were evident (figs. 5, 6, and 7). Conspicuous depressions, which were observed several days prior to the December 21-22, storm, created a more extensive disruption in the bottom microtopography (fig. 7). These depressions may have been associated with burrowing quahogs or with fish feeding, possibly by the cod or haddock observed at this time.

Between December 25 and January 3, the number of mobile epibenthic invertebrates was greatly reduced, with a 70 percent decrease from the previous time period (table 2). With the first intrusion of colder shelf water, the observed detrital cover decreased (fig. 8B). Apparent molluskan depressions deepened during this time and with subsequent cold water intrusions (figs. 8B and 10A). This burrowing behavior, during which Artica islandic may experience periods of self-induced anaerobiosis (Taylor, 1976), may have been in immediate response to the colder water temperature or to other physical and environmental conditions that are discussed later. Renewed detrital cover was evident during the subsequent warm water intrusions.

From January 3 until February 4, when the bottom water temperature was "more constant, mobile epibenthic invertebrates were still greatly reduced in number (table 2). Starfish were most numerous; however, the occurrence of browsers (gastropod and sand dollars) had increased significantly from early winter observations (table 2). Following the January 5 and 8 storms and the subsequent advection of cold shelf water, the detrital cover was nearly gone (fig. 4B).

From February 4 to the end of this winter record, the water temperature slowly increased. Browsers, as well as scavengers and carnivores and their tracks, were more evident. In particular, sand dollars, stars, gastropod, and sea urchins increased significantly (table 2). The large influx of sand dollars observed in February and March was nearly a nine-fold increase from earlier observations (table 2). Pits and depressions, photographed on March 1-3, contributed to the ocean bottom microtopography (fig. 10B). These may have been related to mollusks burrowing or fish feeding, or both. small and large singular holes, observed throughout the record, were probably polychaete burrows or worm tubes.

In summary, the predominant changes in ocean-bottom microtopography in winter were caused by storms and tidal currents, although tracks and pits from benthic invertebrates and fish were evident throughout the winter observation period (figs. 5, 6, 7, 9, and 10). Benthic invertebrates and fish were numerous and diverse during December when the water temperature exceeded 6°C. At this time, a biological mat (detrital cover) seemed to armour and inhibit erosion of the surface sediments. However, depressions caused by burrowing molluskan bivalves (ocean quahogs) and/or fish feeding (figs. 7 and 10) probably did contribute to some disturbance and mixing in the upper sediments.

Spring: Record 126 (April 16-July 8, 1977)

Physical observations

The bottom sediments were relatively undisturbed throughout spring except during the spring tides when current speeds exceeded 30 cm/s {fig. 11). At these times, small ripples and scour were observed in early May (3, 5, 6, 7, 10) and on June 4 (fig. 12A). Small fluctuations in light transmission occurred at the semidiurnal tidal period; however, for the most part, transmission values were high and the photographs were clear which indicates that suspended-matter concentrations were generally low. Temperatures gradually increased from 6°C to 7°C but remained below 8°C. A cross-shelf temperature section made at the beginning of the observation period (fig. 2A) showed the shelf-water/slope-water front well offshore of Station A. At the end of the observation period (fig. 2B), the front was still offshore but a seasonal thermocline had begun to develop and waters were warmer to the north and south.

Biological observations

Nekton

Because the temperature and other physical data did not suggest any distinguishing observation periods, the biological data were analyzed by month. Most fish were observed in May and June; almost none were observed in April and early July (fig. 11, table 3). The predominant fish in May was sculpin, probably longhorn Myoxocephalus octodecimspinosus, the most common sculpin in the Gulf of Maine (Bigelow and Schroeder, 1953). The several sculpin yearlings observed averaged 3.9 inches in length; the older sculpin averaged 12.1 inches in length and were at least 4-6 years old (fig. 12). Fish observations were fewer in June than in May, but the variety increased. Of these, sculpin were again most frequently observed (table 3).

Benthos

Starfish were the most common mobile epibenthic invertebrates observed in April, May, June, and July; however, the scavenging hermit crab Pagurus sp. and a variety of gastropod (browsing snails, sea slugs, and carnivorous whelks) were also frequently observed (table 4, figs. 12-15). Other invertebrates included scavenging crabs, such as Cancer sp., and more sedentary species, including bivalve mollusks and tubeworms.

Biological disturbances of the surface sediments included hermit crab pits (fig. 13), which lasted 3 days; large gastropod tracks and pits (fig. 14

and 15), probably from predacious snails and carnivorous whelks, which lasted 2 days; and small gastropod trails (fig. 12), probably from browsing snails, which lasted less than 1 day. Fecal mounds produced by tubeworms and bivalve mollusks, and burrows made by polychaetes, mollusks, and crabs also contributed to a distinct, although more subtle, biorelief. A moderate (50-75 percent) detrital cover was observed in May, June, and July. Paired siphon holes, most likely of ocean quahogs, and large singular holes, probably from sipunculids or crabs or both, were conspicuous. All these features contributed to the ocean bottom microtopography (figs. 12-16).

Summer: Record 132 (July 9-September 19, 1977)

Physical observations

There were no significant storms during the summer observation period. Scour was observed whenever bottom current speeds exceeded 30 cm/s, generally during spring tides in July and August (fig. 17). The maximum speeds observed were associated with high-frequency internal waves (Butman and others, 1979). Because the transmissometer failed during this period, no quantitative continuous suspended-matter measurement was recorded; however, the photographs indicate changes in suspended matter associated with the high current speeds. Between July 26 and August 6, scour and ripple formation were observed; asymmetric ripples 12-26 cm wide (crest to crest) were observed on July 30. On August 1, when bottom current speeds exceeded 40 cm/s, scour was intense and resulted in complete ripple breakdown and the removal of most detritus (fig. 18A,B). Increased turbidity and resuspension were also observed on August 4 (fig. 18C, D). Between August 22 and 31, scour was again obvious; large increases in turbidity were especially evident on August 27 when bottom current speeds exceeded 40 cm/s. Other frequent scour was .

observed in photographs between September 9 and 16 and was apparently caused by large currents. During strong tidal cycles throughout the observation period, empty bivalve shells were turned from concave-up to the more stable (Emery, 1968) concave-down position (fig. 18).

Throughout the summer observation period, the water temperature gradually increased from about 7°C to 14°C. During this gradual increase three sharp temperature increases were observed (fig. 17). On August 8 and 9 the temperature increased rapidly from about 8.5 to 10°C. On August 28, a second sharp increase in temperature from about 10 to 11.5°C was observed. Temperatures steadily increased through September. However, temperature fluctuations of 1-2°C occurred between September 3-6 and 16-18. These warm intrusions may be southward advection of the well-mixed bank water or advection and down welling of slope water (figs. 2B, 2C). The hydrographic section taken in September, 1977 (fig. 2C) suggests that at that time, the water at Station A was a complex mixture of shelf and slope water. Subsequent analysis indicates that Gulf Stream meander R and eddy Q contributed to the extreme warm water observed (Flagg and others, 1982; Butman and Beardsley, 198_). The rapid changes in temperature imply local fronts and movement of these fronts past the mooring.

Biological observations

Nekton

Because the temperature measurements showed distinct warm-water intrusions which may have affected the number or variety of fish observed in the area, the data were analyzed for selected periods (fig. 17, table 5). Overall the predominant fish observed throughout the summer were hake *Urophycis* spp. and cod *Gadus callarias* with most observations made in August and September (table 5, fig. 17). Few fish were observed in July when the water temperature was generally below 9°C (fig 17).

Rake and cod were the major species observed in the four weeks prior to the first sharp increase in water temperature on August 8 (fig. 17, table 5). Hake averaged 15.2 inches in length (2-3 years old) and cod averaged 24.7 inches in length (4 years old). During this time an increase in the number of fish was apparent in early August (fig. 17). After August 8, the number and diversity of fish continued to increase and in the following 3 weeks (August 8-27) six species of fish were identified: hake, cod, sculpin <u>Myoxocephalus octodecimspinosus</u>, eel <u>Omochelys cruentifer</u>, sea raven <u>Hemitripterus americanus</u>, arid ocean pout <u>Macrozoarces americanus</u> (table 5, figs. 19 and 20). Hake averaged 28.8 inches in length, older than 3 years. This larger hake group may include the larger white as well as red hake. Cod averaged 26.4 inches in length, mostly 4 years old. The sculpin averaged 11.5 inches in length and were mature 6-year-olds.

Following the second sharp Increase In temperature on August 28, fish continued to be prevalent (fig. 17). -However, it was not until the warm water intrusions in early Septmeber (3-6) and again in mid-September (16-18) that a conspicuous increase in fish number and diversity was observed (fig. 17, table 5). The number of fish observed were tabulated for three intervals in late August and early September; the average number of fish observed each day nearly doubled during these selected time periods (table 5). This pattern of increased fish number and diversity apparent in September was similar to that observed in December when warm slope water occupied Station A (fig. 3; table 1).

Hake was the predominant fish from August 28 to September 18 (table 5). These hake averaged 27.6 inches in length and were 3 years old and older. The next most common fish was ocean pout (fig. 20 B). Cod were the next most frequently observed commercial fish; these fish averaged 25.9 inches in length and were thus 4-5 years old. Other fish observed were sea raven, sculpin, eel, and goosefish (table 5).

Benthos

Scavengers (hermit crabs, Cancer crabs) and browsers (gastropod, slugs), similar to those species seen during the spring observations period, were evident throughout the summer (figs. 20, 21 and 22; table 6). Again starfish were the most common mobile epibenthic invertebrates observed. Paired siphon holes, probably of ocean quahogs, and large and small singular holes, probably from polychaetes, sipinculids, and crabs were also common.

A biological mat, similar in coverage and appearance to the mat previously observed during the warm period in early December, dominated the ocean bottom microtopography (fig. 22). Conspicuous fecal mounds contributed to a surficial floccy layer that was superimposed on the moderate to extensive mat. Biologically induced disturbances in this mat were apparent throughout the observation period (figs. 19-22). The tracks, pits, and burrows of hermit crabs and Cancer crabs contributed to the ocean bottom microtopography (figs. 20, 21, and 22). Other biological disturbances of the surface sediments were associated with burrowing and feeding activities of the more sedentary benthic invertebrates (figs. 19-22).

DISCUSSION

Nekton

The importance of temperature in determining the distribution of fish and their seasonal abundance has been long recognized by fishery biologists.

However, it has repeatedly proven difficult to document the implied causality between temperature and seasonal abundance (Edwards, 1964). Seasonal trends for important commercial groundfish species have been observed in large-scale fall and spring groundfish surveys conducted by the National Marine Fisheries Service (Grosslein and Bowman, 1973; Grosslein and Clark, 1976). Our data suggest that on local scales seasonal trends of species and abundance of fish are correlated with the seasonal cycle of temperature and with the local temperature fluctuations which may be associated with fronts (figs. 23 and 24). This also implies that temperature preferences exist among species of fish.

In our analysis fish were most abundant and diverse in late summer (August and September) and early winter (December) when the water temperature exceeded 9°C (figs. 3, 17, and 23). Unfortunately, there is no data to determine if this trend continued through the fall. Hake, the red and white ling species, were the predominant fish during these warm periods (fig. 23, tables 1 and 5). Red hake, along with many other groundfish species, appear to demonstrate a warm water preference (Edwards, 1964). They are known to be aggregated south and offshore in deep-water wintering areas beyond the shelf break (100 m) during late winter and spring months concomitant with their spawning season (Bigelow and Schroeder, 1953; Grosslein and Bowman, 1973; Hare, 1977). For this area, slope water temperatures are at least 10°C throughout the year and reach a maximum of 12-14°C between 100-125 m (Edwards, 1964).

Unlike hake, cod were observed throughout the winter (fig. 23, table 1). The largest number of cod was observed in late December and early January (December 25-January 2) during the winter cooling and offshore movement of the shelf-water/slope-water front (table 1). The shift in species from hake to cod (table 1) simultaneous with the temperature shift from warm to cold suggests that hake prefer the warmer slope water, while cod prefer the cooler shelf water. The appearance of cod in August and September (table 5) shows that these fish also occur in warm waters near local fronts. This suggests that the cod distribution pattern is more complex and that temperature perturbations may partially control their movements. Our data are consistent with the southeasterly shift for cod across Georges Bank between fall and spring reported by the National Marine Fisheries Service (Grosslein and Bowman, 1973; Grosslein and Clark, 1976).

The other predominant fish observed was sculpin, probably longhorn (fig. 23, table 3). This specie, both adult and yearlings, dominated the nekton in the spring. Their occurrence in May might reflect a southeastward movement of fish from the crest of Georges Bank. Bigelow and Schroeder (1953) have reported offshore migration of sculpin from warm shoal waters in May, possibly to cooler waters for the summer. Sculpin were also predominant with cod in winter (fig. 23) which suggests this specie may have a similar cold water preference.

The only other nekton specie worth comment is the squid observed in December (table 1). Preliminary catch data from the National Marine Fisheries Service indicates that squid demonstrate temperature preferences (A. Lang, personal commun., 1981). Their singular appearance one day prior to the first shelf water intrusion suggests that they may have been associated with the inshore boundary of the shelf-water/slope-water front. Squid are known to migrate from the shelf in late autumn to oceanic spawning areas (Vinogradov and Noskov, 1978).

In our data, the greatest variety and number of fish were observed in December when the shelf-water/slope-water front was located near Station A (fig. 3, table 1) and in August and September when warmer water advected past the mooring in apparent local fronts (fig. 17, table 5). At both these times there were large temperature fluctuations at Station A (figs. 3 and 17). It has been suggested that demersal and semi-demersal fish may migrate and show the same variable features with frontal-conditions that have been hypothesized for pelagic fish (Steele, 1980). Within the frontal region nutrient-rich waters would be expected to enhance primary productivity (Fournier and others, 1977) and ultimately result in higher aggregations of pelagic fish (Schroeder, 1955); moreover, sharp changes in the physical environment near the ocean bottom might be expected to affect benthic food supplies for demersal fish (Laevastu and Hela, 1970; Laevastu and Hayes, 1981). In our data, the proximity of a sharp thermal front is indicated by the variability of temperature; fish were most numerous when the temperature variability was greatest (fig. 24). The high linear regression coefficient of .93, higher than that found for mean temperature (.84), suggests that temperature variability (u_T) was correlated and important in determining the fish distributions. The observed "waves" of nekton, especially obvious in the case of cod and squid (figs. 3 and 8), may reflect an association with fronts. As Laevastu and Hela (1970) first proposed, this might reflect a response to available benthic food supplies and changing ocean bottom conditions near fronts.

Benthos

In contrast, the benthic community was less variable in both the number of individuals and the variety of species throughout the three seasons with the exception of February and March. There was no obvious temperature correlation with seasonal abundance and species predominance (fig. 23);

however, the photographic data does suggest a seasonal temperature dependence in benthic activity. Predominant benthic invertebrates were burrowers, scavengers, and browsers that are common in a detrital sand environment (Emery and others, 1965; Emery and Uchupi, 1972).

Thick-shelled pelecypods (ocean quahogs) and worms (polychaetes and sipunculids) were the active burrowers. They may have contributed to the reworking of the upper (-10 cm) surficial sediments that was obvious in early winter, spring, and summer. In particular, molluscan depressions were conspicuous features and were observed to deepen as pits, especially in late December. This deeper burrowing behavior may have been a response to cold temperatures, storms, and/or the wave scour frequent at this time (Breum, 1970). Ocean quahogs are also known to exhibit a predator-prey escape response (Taylor, 1976) and young cod, common in late December, may have initiated the deeper burrowing. The reduced detrital cover suggested that molluscan filter feeding and food utilization were also greatly reduced at temperatures below 6°C. Reduced feeding rates at low temperatures have been reported for other common lamellibranchs (Galstoff, 1928; Hopkins, 1931; Menzel, 1955; Kinne, 1963; Kinne, 1967; Walne, 1972).

Scavengers, browsers, and carnivores were the most common mobile epibenthic invertebrates (fig. 23). Overall, starfish were dominant; their abundance supports the existence of a plentiful molluskan food supply. Browsing snails and slugs and carnivorous whelks were the dominant gastropod in spring and early summer. Scavenging hermit crabs were also frequently observed in spring. The highest abundances in mobile benthic invertebrates were recorded in February and March (fig. 23). The large influx of sand dollars observed shuffling through the loose sediment contributed significantly to this maximum (fig. 23, table 2). The reason for their sudden increase is unknown, but they may have been in migration from the shallower bank waters following winter cooling.

In summary, mobile epibenthic invertebrates were most abundant February through July; whereas, In later summer and early winter (August, September, December, and January) their numbers were markedly reduced (fig. 23). When numbers of fish and invertebrates are viewed simultaneously, an inverse relationship is implied (fig. 23). Numbers of invertebrates were highest when numbers of fish were lowest and vice-versa. This Inverse relationship may indicate a predator-prey response by the mobile invertebrates.

The observed seasonal activity in benthic invertebrates was important to seasonal changes in mixing, erodibility, and resuspension of the surficial sediments. At Station A, the benthic assemblage was grossly composed of suspension-feeding mollusks, tube-dwelling polychaetes, and tube-dwelling amphipods (F. Grassle, personal commun., 1981) which can act as stabilizers by binding sediments and Inhibiting erosion (Rhoads and others, 1978a; Rhoads and others, 1978b; Yingst and Rhoads, 1978). Their fecal matter probably contributed largely to the detrital component of the biological mat. Rhoads and others (1978a) have identified mucous exudates secreted by microorganisms and larger benthic invertebrates which bind and stabilize the surficial sediments. Aggregates of tubes and microbial growth which promote mucous binding, can increase the critical entrainment velocity as much as 45 percent in sand environments (Newell and others, 1981; Grant and others, 1982). Mat-bound sandy carbonate sediments have been found to withstand current velocities two to five times as high as those that erode unbound sediments (Neumann and others, 1970; Scoffin, 1970).

At StatIon A, the biological mat was most extensive (75–90 percent) when the water temperature was warm (>10°C). After the winter cooling, this mat was almost absent, presumably eroded by intense storms. The mat was not reestablished at temperatures below 6°C, and winter storms as well as tidal currents were sufficient to rework the unbound surficial sediments and shell debris. As the water gradually warmed in spring and summer and storms became less intense, a moderate to extensive (50-90 percent) biological mat was reestablished and only the strong spring tides and summer internal waves were competent to scour the surface sediments. However, a light flocculent organic material on the surface of the mat was very easily eroded and resuspended.

Benthic invertebrates probably contributed to surface sediment mixing with their tracks, pits, and scratches, as well as by their burrowing activity. Tracking, in particular, can result in a 20 percent decrease in critical entrainment velocities (Newell and others, 1981). The sporadic burrowing activity of mollusks in late December probably contributed substantially to the increased erodibility of surface sediments during winter. By changing the bulk character of the sediments, an increase in porosity and water content would occur (Postma, 1967). Bioturbation, which can lower the critical entrainment velocity as much as 25 percent, is an important variable in the stability of sand environments (Newell and others, 1981; Grant and others, 1982).

The time-series photographs obtained from the bottom tripod systems document changes in the nekton and mobile benthic invertebrates, as well as changes in the ocean bottom microtopography and the surficial sediment movement. In this paper, we have described these changes at one location on Georges Bank for a 10 month period, and attempted to relate these changes to seasonal changes in water temperature, the location of fronts, and to the frequency of sediment movement. The use of the tripod as a haven or habitat by the benthic community is unresolved, and obviously limits quantitative interpretation of the observations. However, the tripod was not immediately swamped with nekton after deployment, and the numbers of mobile benthic Invertebrates and nekton remained constant when the tripods were redeployed. Preliminary analysis of other time-series photographs from tripod deployments at other locations suggest that when physical variables ar'e relatively stable, nekton tend to frequent the tripod frame more or less on a random basis (C. Bryden and K. Orr, unpubl. data, U.S.G.S. Woods Hole, Mass.). In addition, the migrating patterns of fish as inferred from the U.S.G.S. photographs are in qualitative agreement with the NMFS groundfish survey results. These observations suggest that at least the observed trends in seasonal abundance and diversity are representative of changes locally near the tripod system.

Modifications to the tripod system for future biological experiments could easily be made. For example, additional cameras could be attached to the frame, the picture rate could be increased, the camera height or angle could be changed to enlarge the field of view, or the camera height could be lowered to provide more detailed bottom observations. Multiple tripods could be deployed to examine changes on a regional scale. An experiment to directly address the use of the tripod as a habitat would certainly be appropriate before additional studies are made. Bottom tripod observations could be useful in a more detailed study specifically designed to address the relationship between sediment movement and the benthic community.

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Figure 1. Location of U.S. Geological Survey mooring at Station A, Georges Bank.

Figure 1

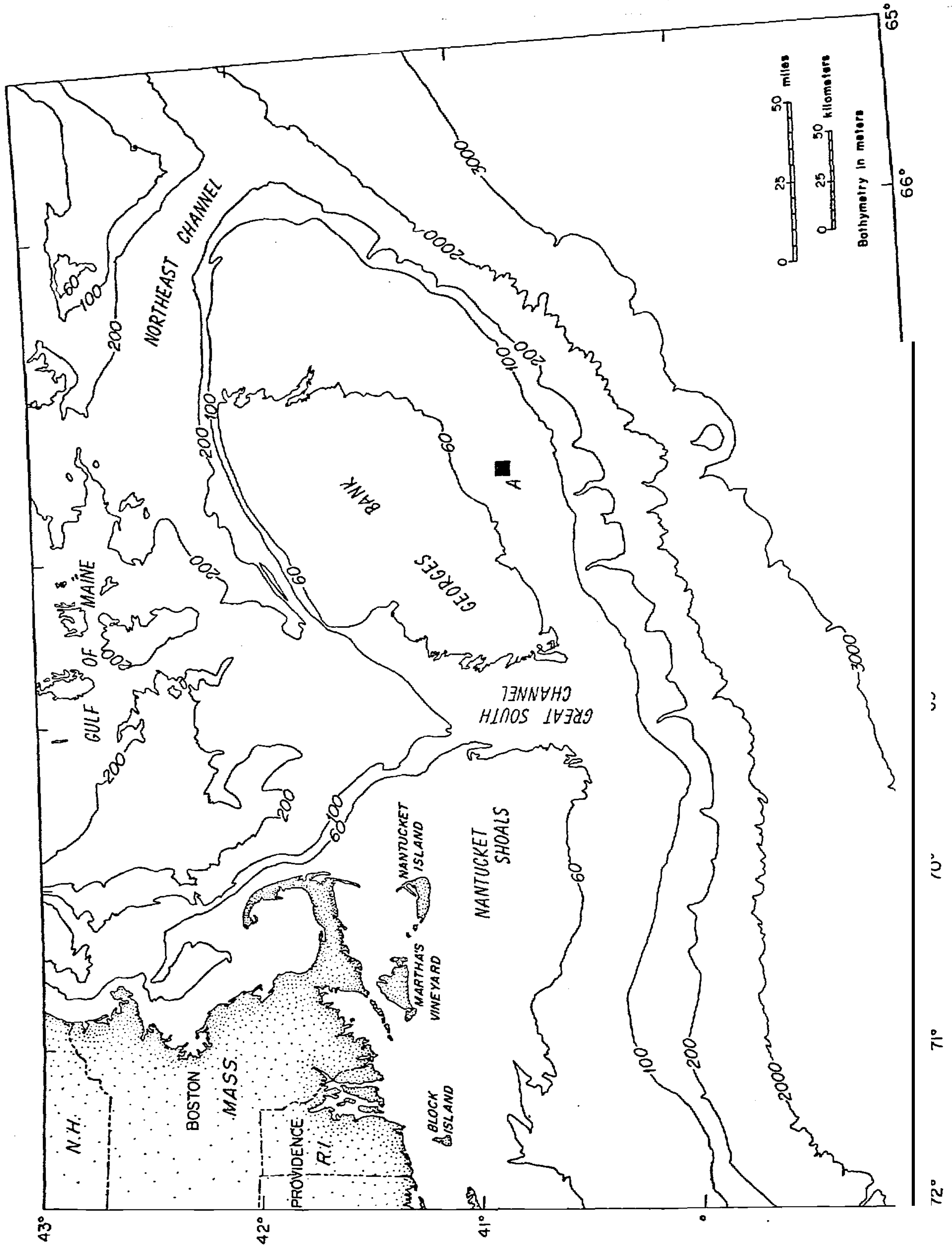

GULF OF MAINE
NORTHEAST CHANNEL
GEORGES BANK
GREAT SOUTH CHANNEL
NANTUCKET SHOALS
NANTUCKET ISLAND
MARTHA'S VINEYARD
BLOCK ISLAND
BOSTON
MASS.
PROVIDENCE
R.I.
N.H.
A
0 25 50 miles
0 25 50 kilometers
Bathymetry in meters
60
100
200
2000
3000
43°
42°
41°
72°
71°
66°
65°

Figure 2. Hydrographic sections across the southern flank of Georges Bank:

a. Fall, winter, spring 1976-1977.

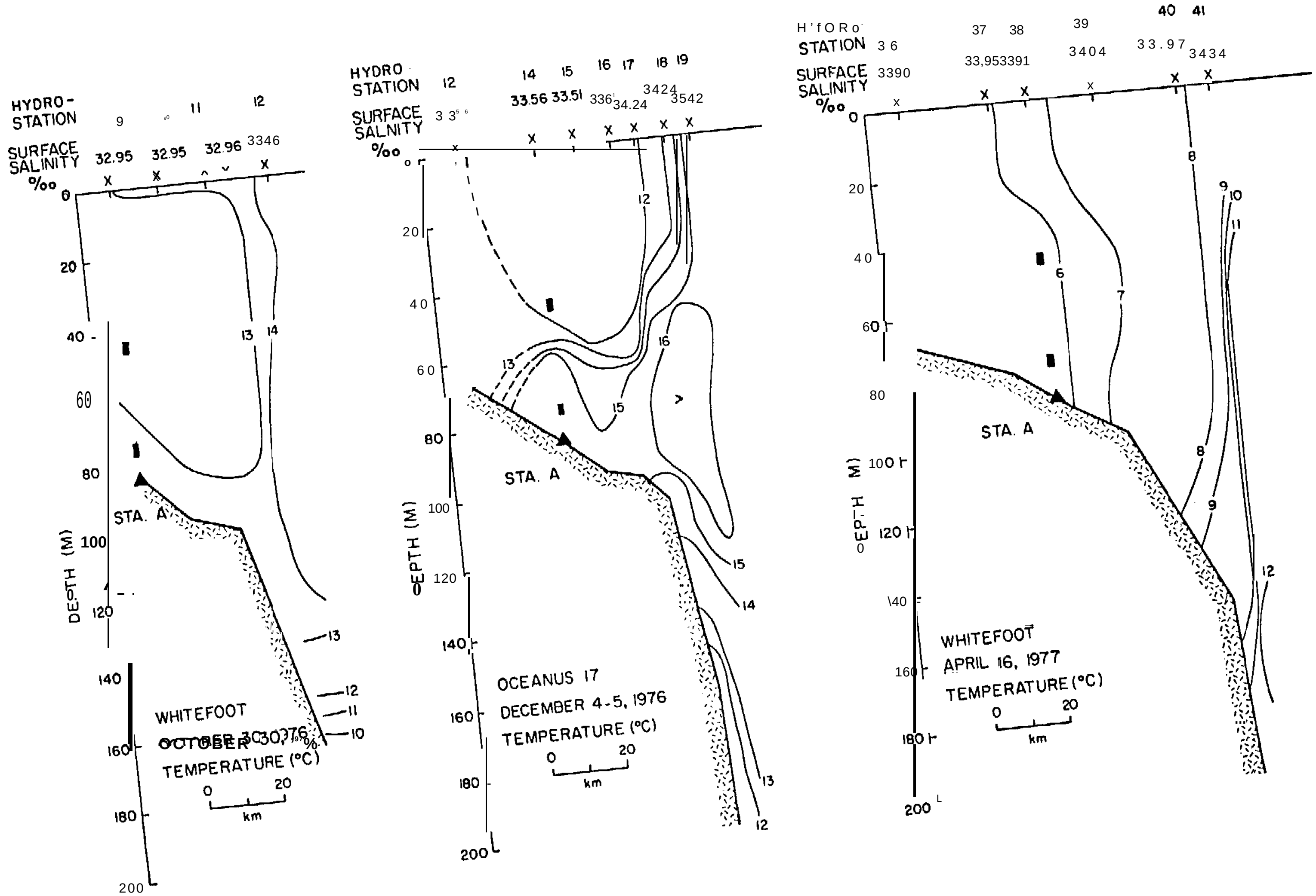

HYDRO-STATION
SURFACE SALINITY ‰
DEPTH (M)
STA. A
WHITEFOOT
OCTOBER 30, 1976
TEMPERATURE (°C)
km
OCEANUS 17
DECEMBER 4-5, 1976
TEMPERATURE (°C)
km
WHITEFOOT
APRIL 16, 1977
TEMPERATURE (°C)
km

Figure 2. Hydrographic sections across the southern flank of Georges Bank:

b. Summer 1977.

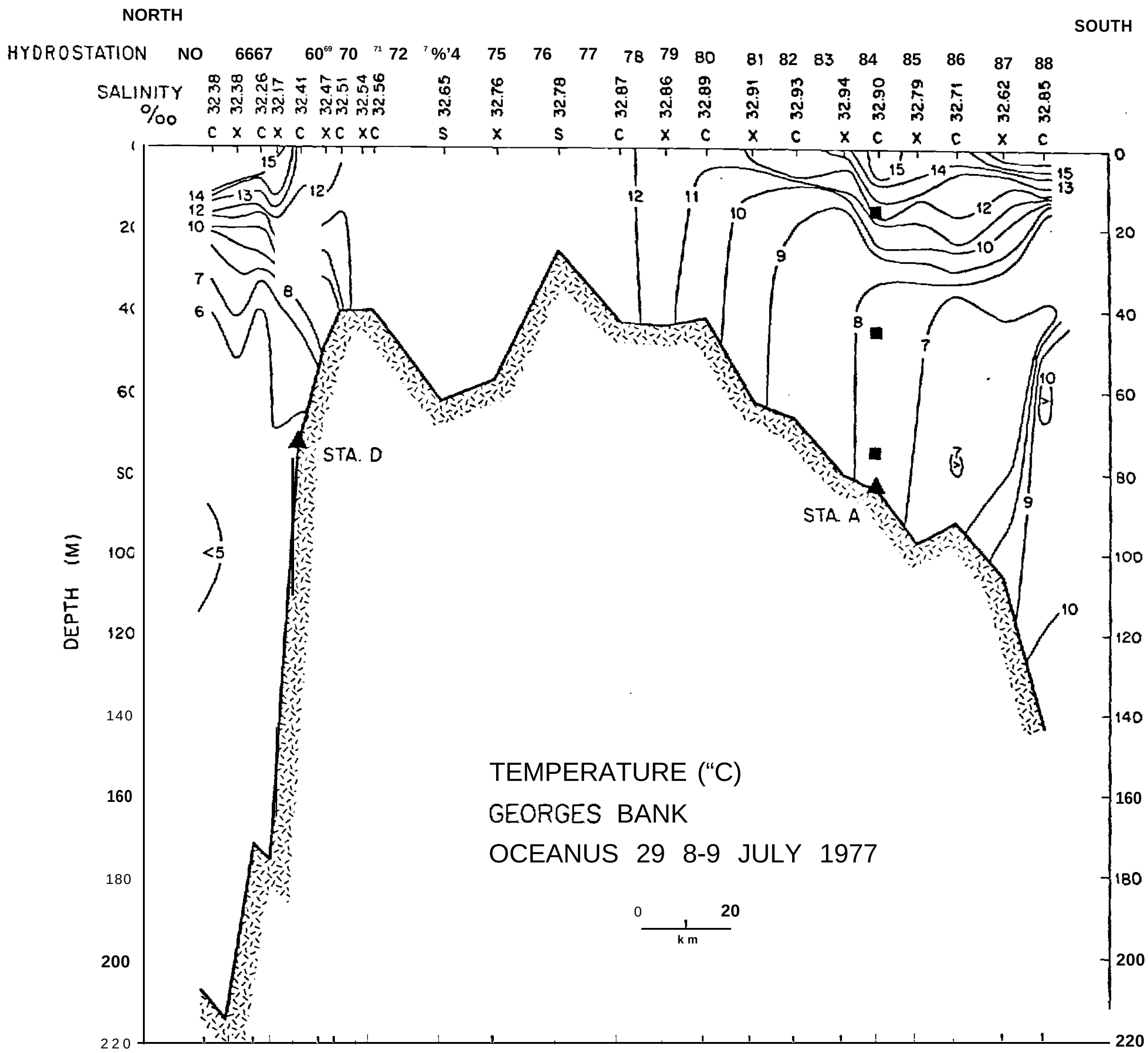
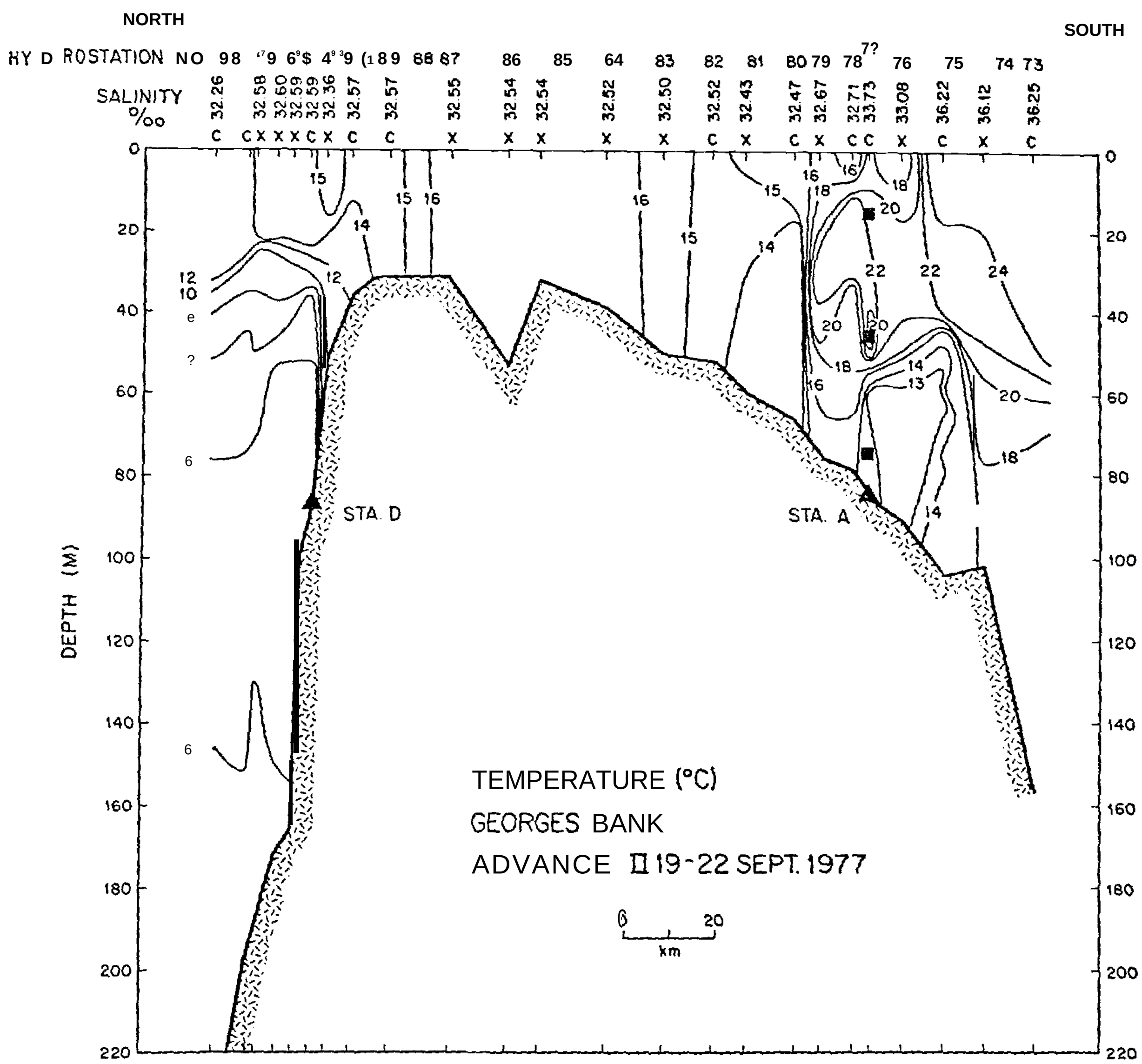

NORTH
SOUTH
HYDROSTATION NO
SALINITY ‰
STA. D
STA. A
DEPTH (M)
TEMPERATURE (°C)
GEORGES BANK
OCEANUS 29 8-9 JULY 1977
0 20
km

Figure 2. Hydrographic sections across the southern flank of Georges Bank:

c. Fall 1977.



NORTH
SOUTH
HYDROSTATION NO
SALINITY ‰
STA. D
STA. A
DEPTH (M)
TEMPERATURE (°C)
GEORGES BANK
ADVANCE II 19-22 SEPT. 1977
0 20
km

Figure 3. Winter tripod observations from December 1976 to February 1977 (Record 120) at Station A, Georges Bank. Fish and invertebrates (mobile epibenthic) represent the total number observed each day from bottom photographs taken every 4 hours. Temperature, relative light transmission, pressure standard deviation (PSDEV), current speed, and pressure plots are made from hour-averaged data.

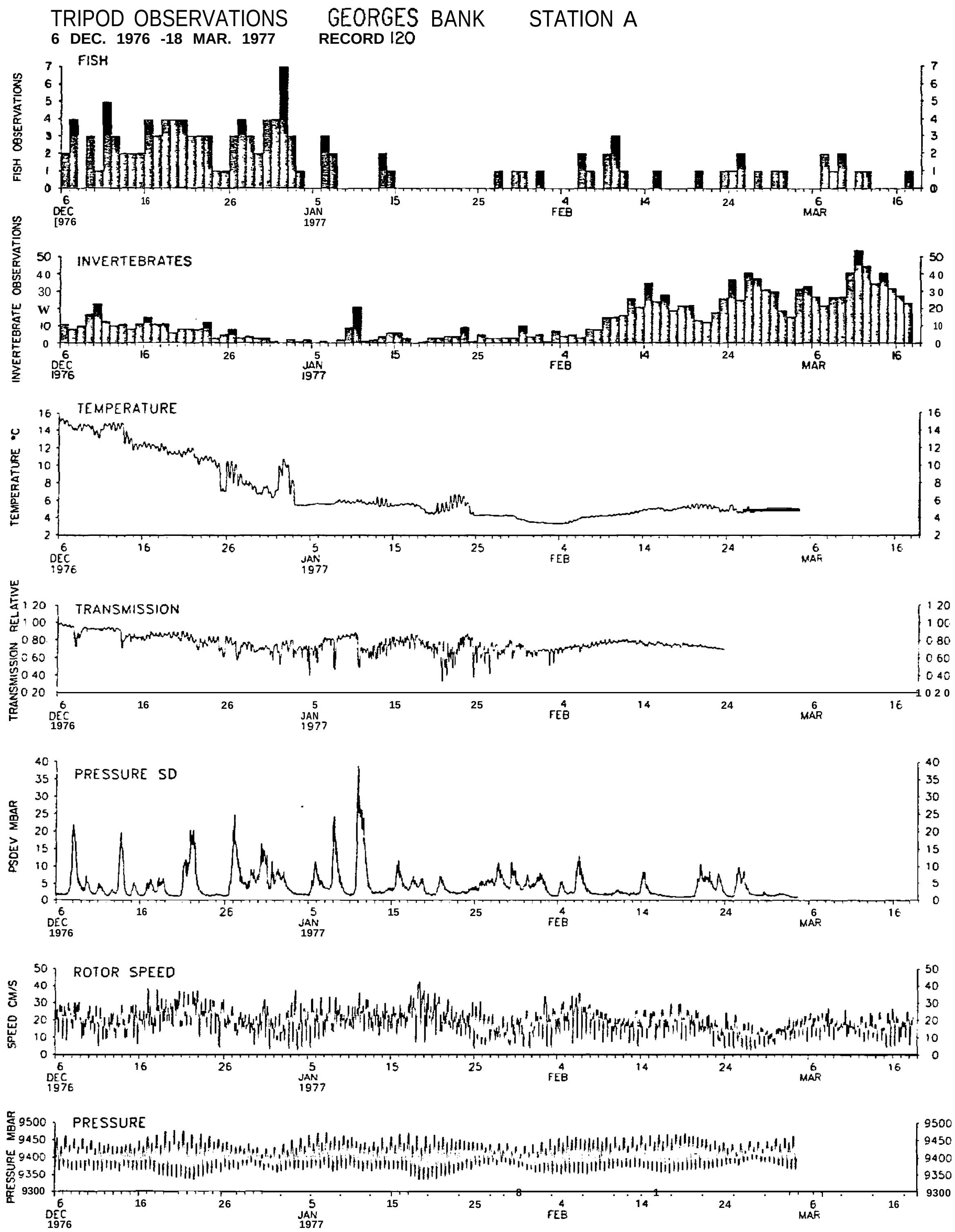

TRIPOD OBSERVATIONS GEORGES BANK STATION A
6 DEC. 1976 -18 MAR. 1977 RECORD 120
FISH
FISH OBSERVATIONS
INVERTEBRATES
INVERTEBRATE OBSERVATIONS
TEMPERATURE
TEMPERATURE °C
TRANSMISSION
TRANSMISSION RELATIVE
PRESSURE SD
PSDEV MBAR
ROTOR SPEED
SPEED CM/S
PRESSURE
PRESSURE MBAR
DEC 1976
JAN 1977
FEB
MAR

Figure 4. Winter bottom microtopography in response to waves and tidal currents.

A. Resuspension.

B. Asymmetric ripples during storm event (PSDEV <25) on January 8.

C. Symmetric ripples during storm event (PSDEV >25) on January 11.

D. Typical asymmetric ripple bed form in February and March in response to tidal currents.

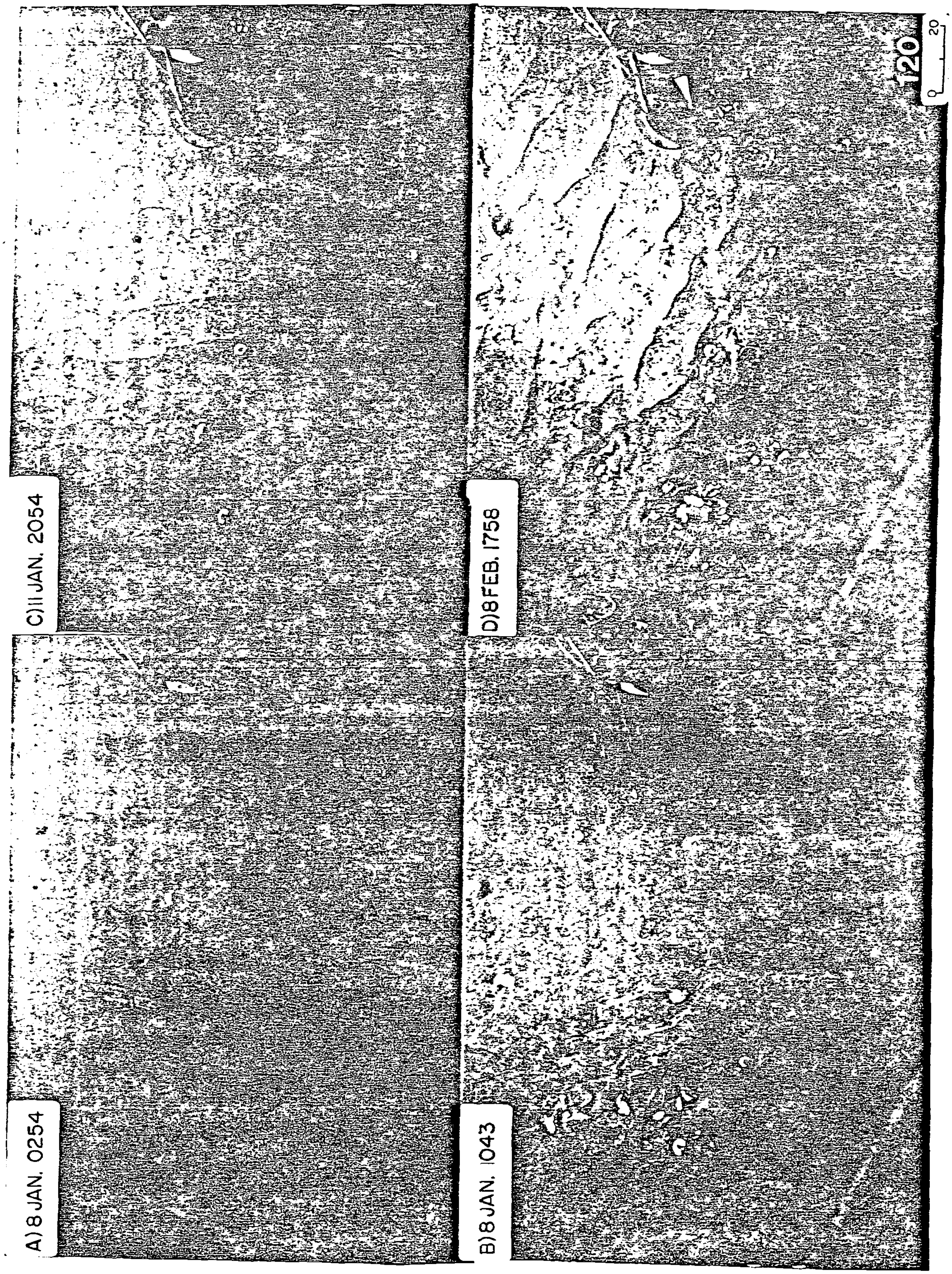

A) 8 JAN. 0254
B) 8 JAN. 1043
C) 11 JAN. 2054
D) 8 FEB. 1758
120
0
20

Figure 5. A. Hake (*Urophycis* spp.) feeding with feelerlike ventral fins extended.

B. Hake feeding track with surface sediment disturbance visible across bottom.

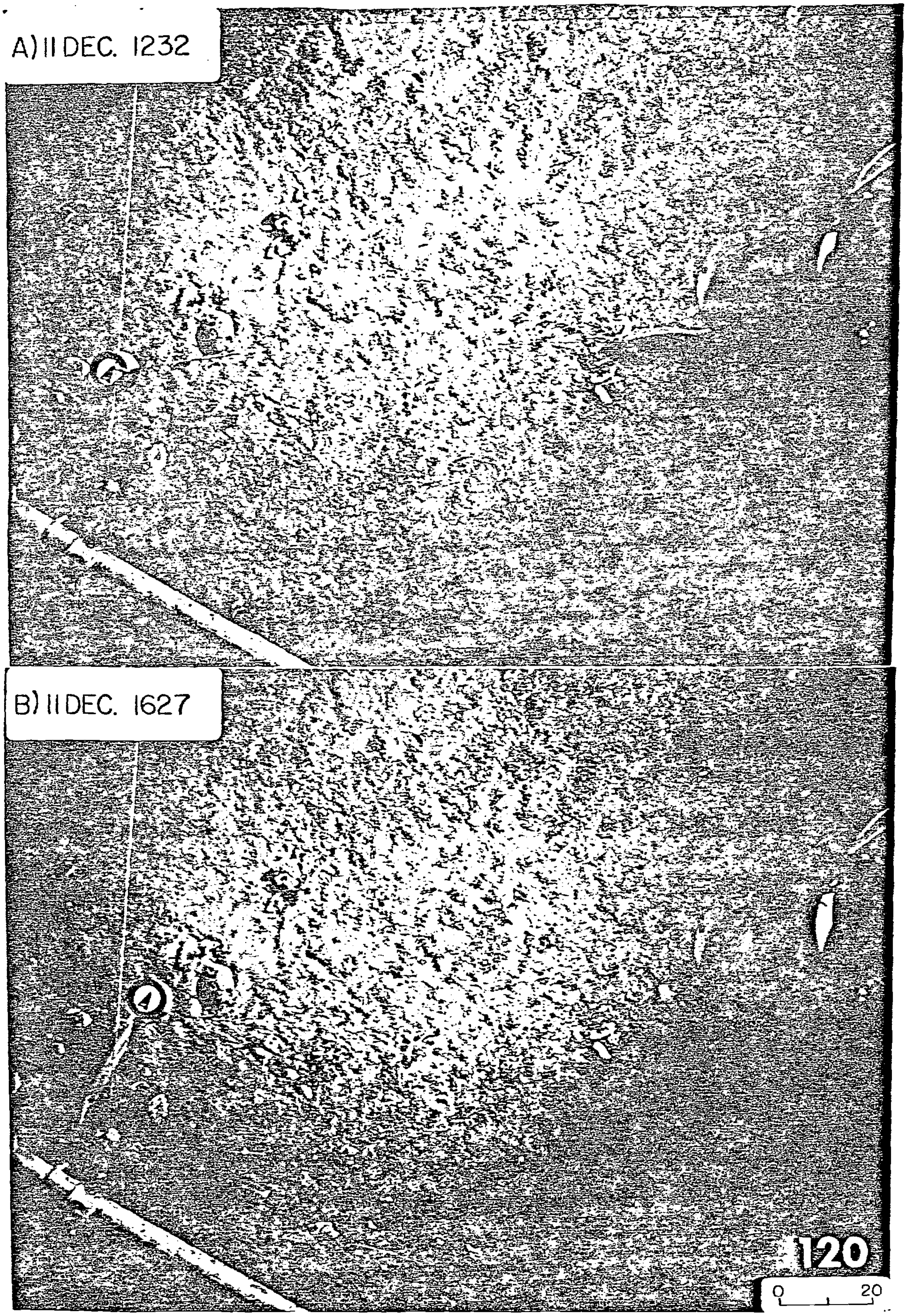

A) 11 DEC. 1232
B) 11 DEC. 1627
120
0
20

Figure 6. A. Goosefish (Lophius americanus) inhabiting its burrow.

B. Conspicuous depression-burrow of temporarily absent goosefish.

Figure 6

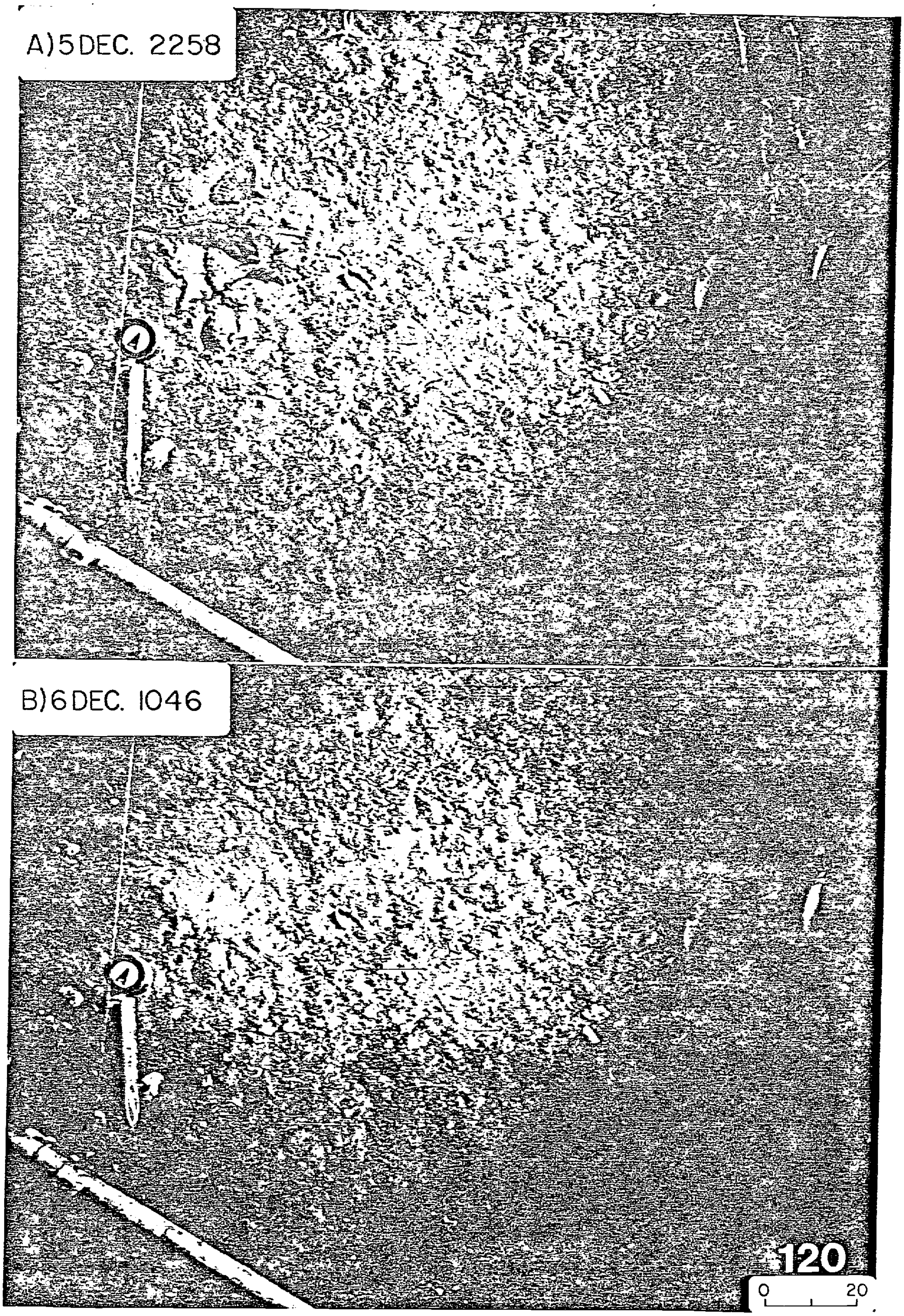


Figure 7. Conspicuous depressions made by fish feeding and/or mollusks burrowing prior to the December 21-22, 1976 storm.

A. Young cod (Gadus callarias).

B. Young haddock (Melanogrammus aeglefinus).

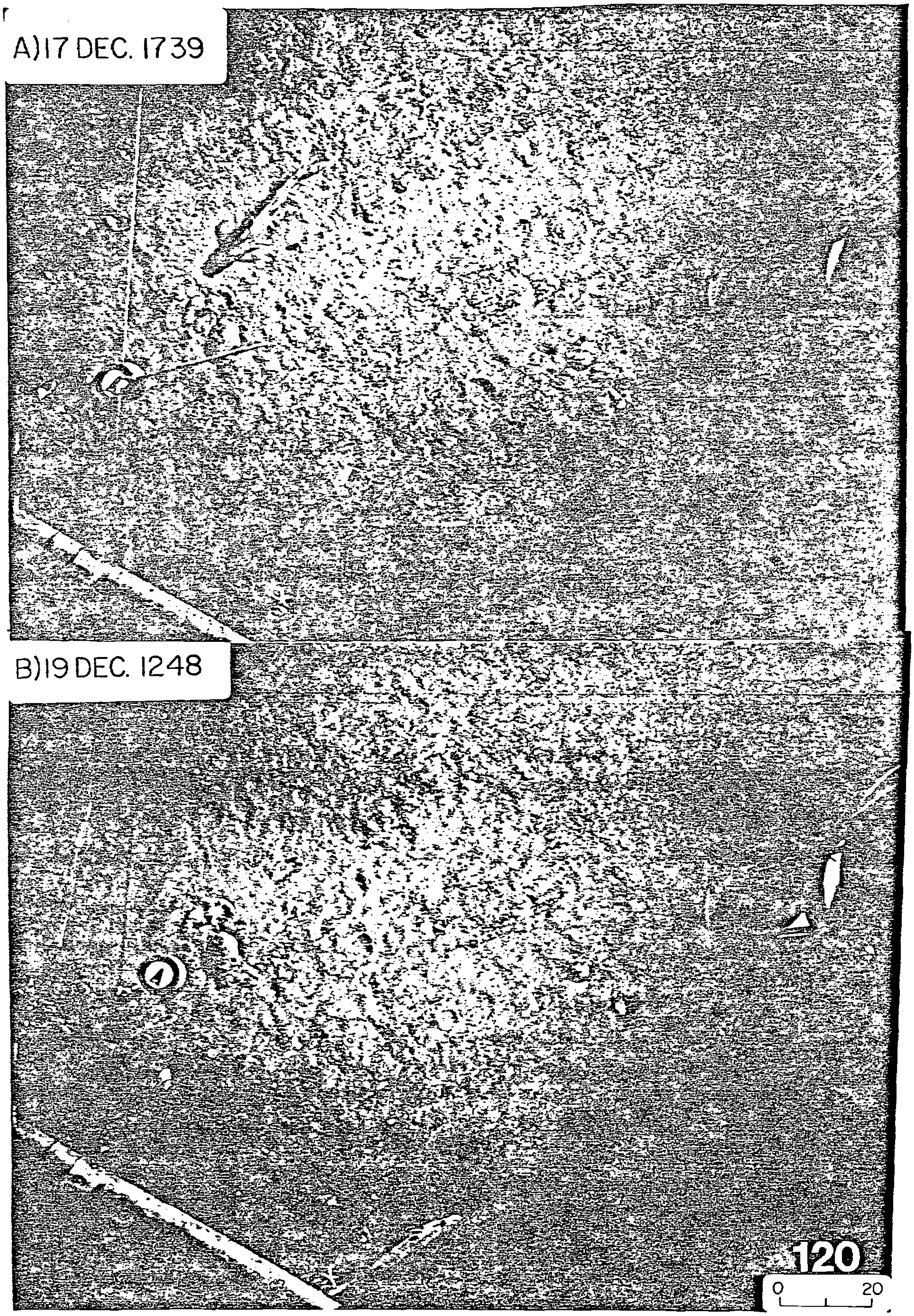

A)17 DEC. 1739
B)19 DEC. 1248
120
0
20

Figure 8. A. Squid (Loligo pealii) observed when shelf-water/slope-water front was near Station A.

B. Young cod (Gadus callarias) commonly observed near shelf-water/slope-water front.

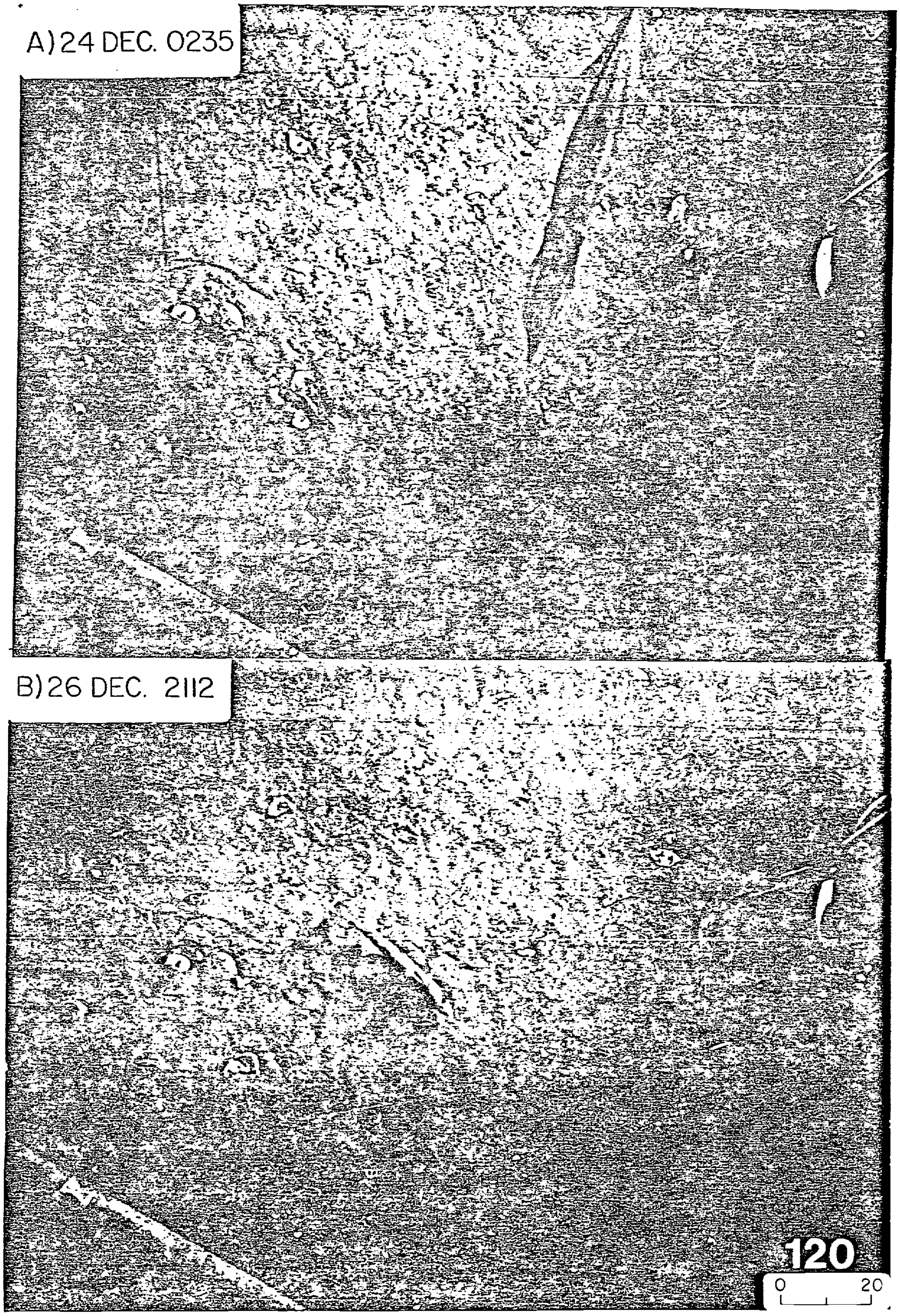

A) 24 DEC. 0235
B) 26 DEC. 2112
120
0
20

Figure 9. A. Typical winter bottom with asymmetric ripples and shell debris accumulated in ripple troughs. Paired siphon holes of ocean quahogs (Arctics islandica) are numerous and clearly visible. Cod (Gadus callarias), also shown, is the predominant winter fish.

B. Typical early winter (December) bottom with extensive detrital mat. Hermit crab (Pagurus) is visible along with gastropod tracks. Paired siphon holes of ocean quahogs (Arctics islandica) are less conspicuous but still visible.

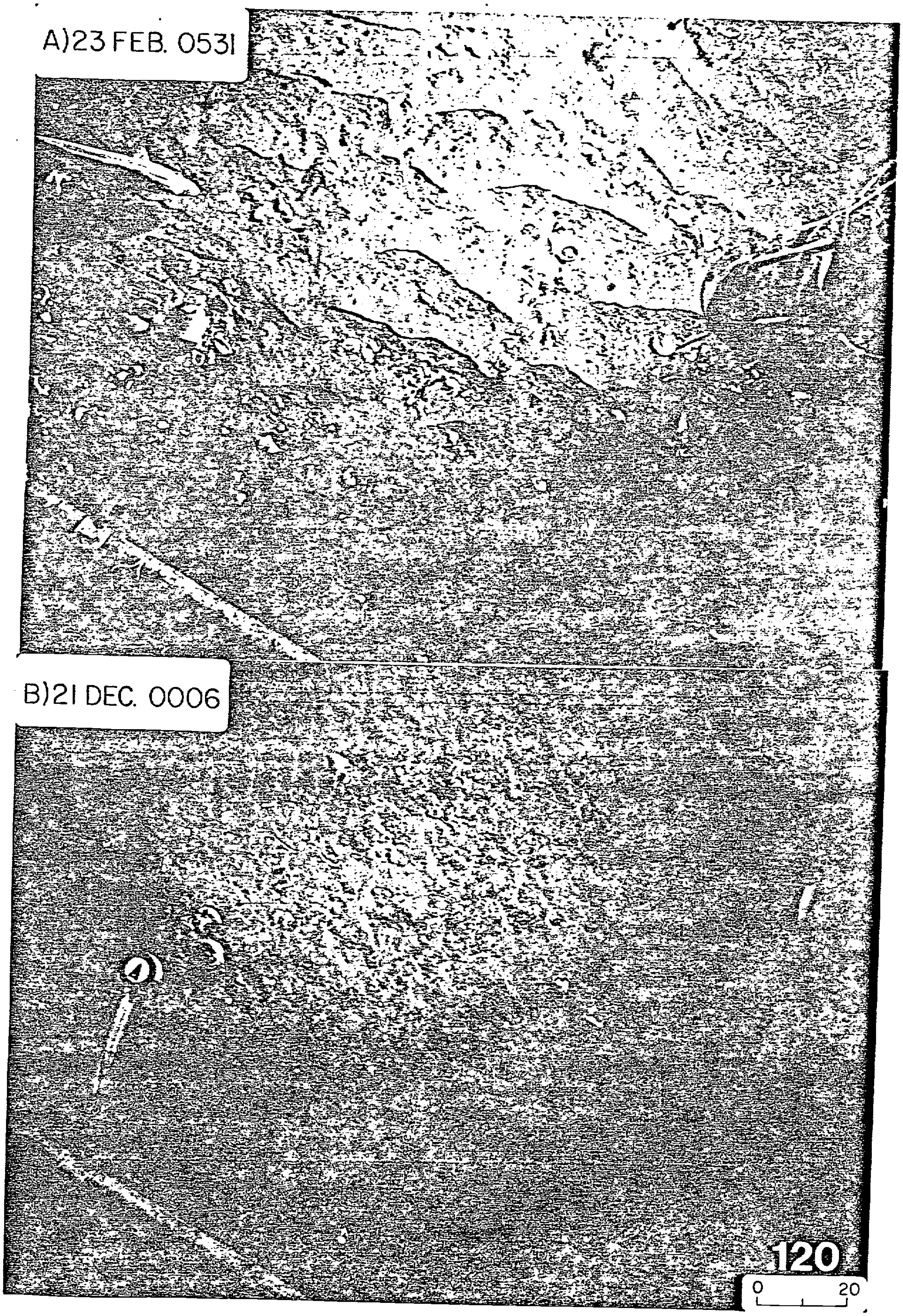

A)23 FEB. 0531
B)21 DEC. 0006
A
120
0
20

Figure 10. A. Deepened molluskan depressions associated with cold turbid shelf water intrusions.

B. Conspicuous depressions made by fish feeding or mollusks burrowing, or both, during March 1-3, 1977. Cod (*Gadus callarias*), predominant winter fish, is shown.

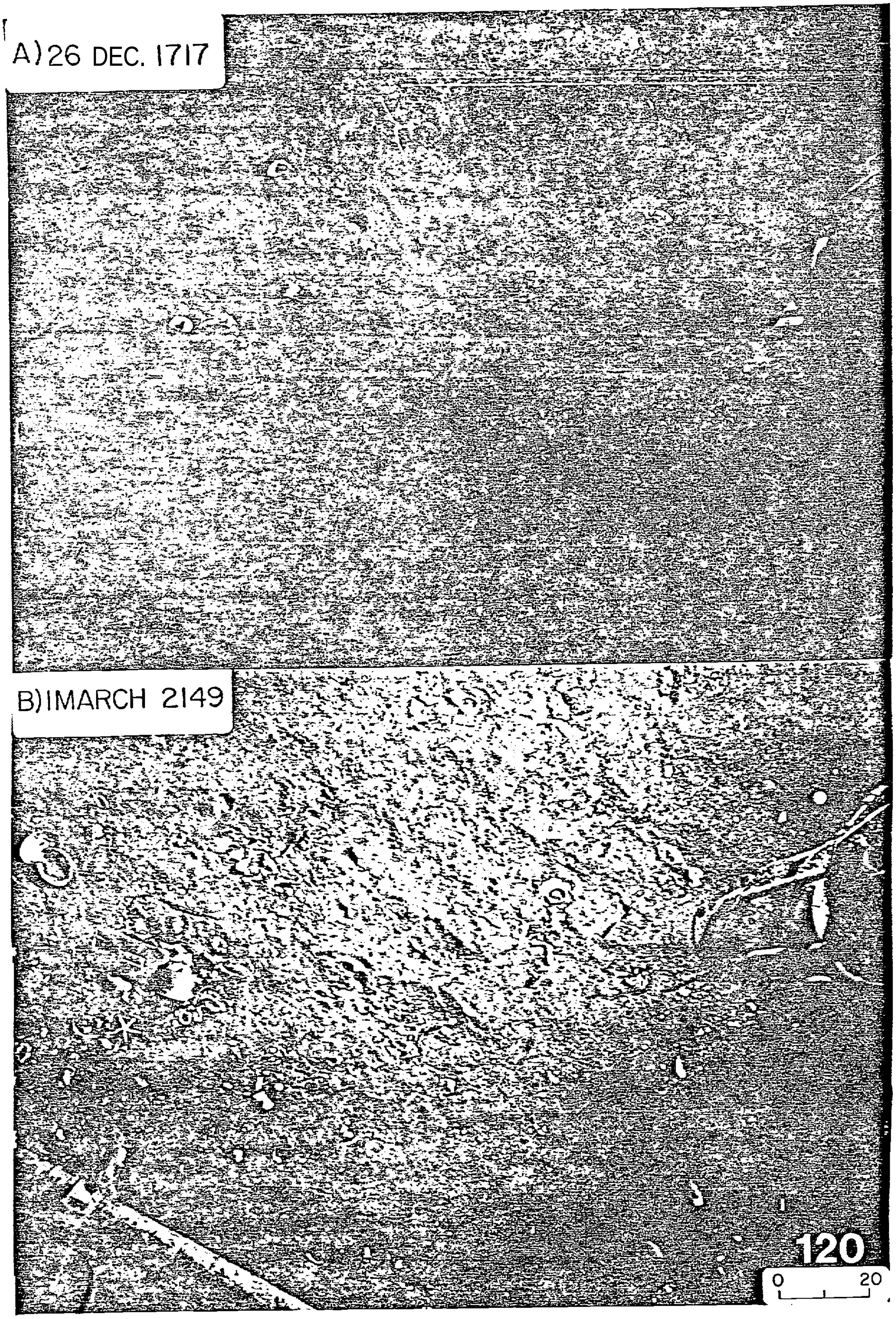

A) 26 DEC. 1717
B) 1MARCH 2149
120
0
20

Figure 11. Spring (and early summer) tripod observations from April to June 1977 (Record 126) at Station A, Georges Bank. Fish and invertebrates (mobile epibenthic) represent the total number observed each day from bottom photographs taken every 4 hours. Temperature, relative light transmission, pressure standard deviation (PSDEV), current speed, and pressure plots are made from all available hour-averaged data.

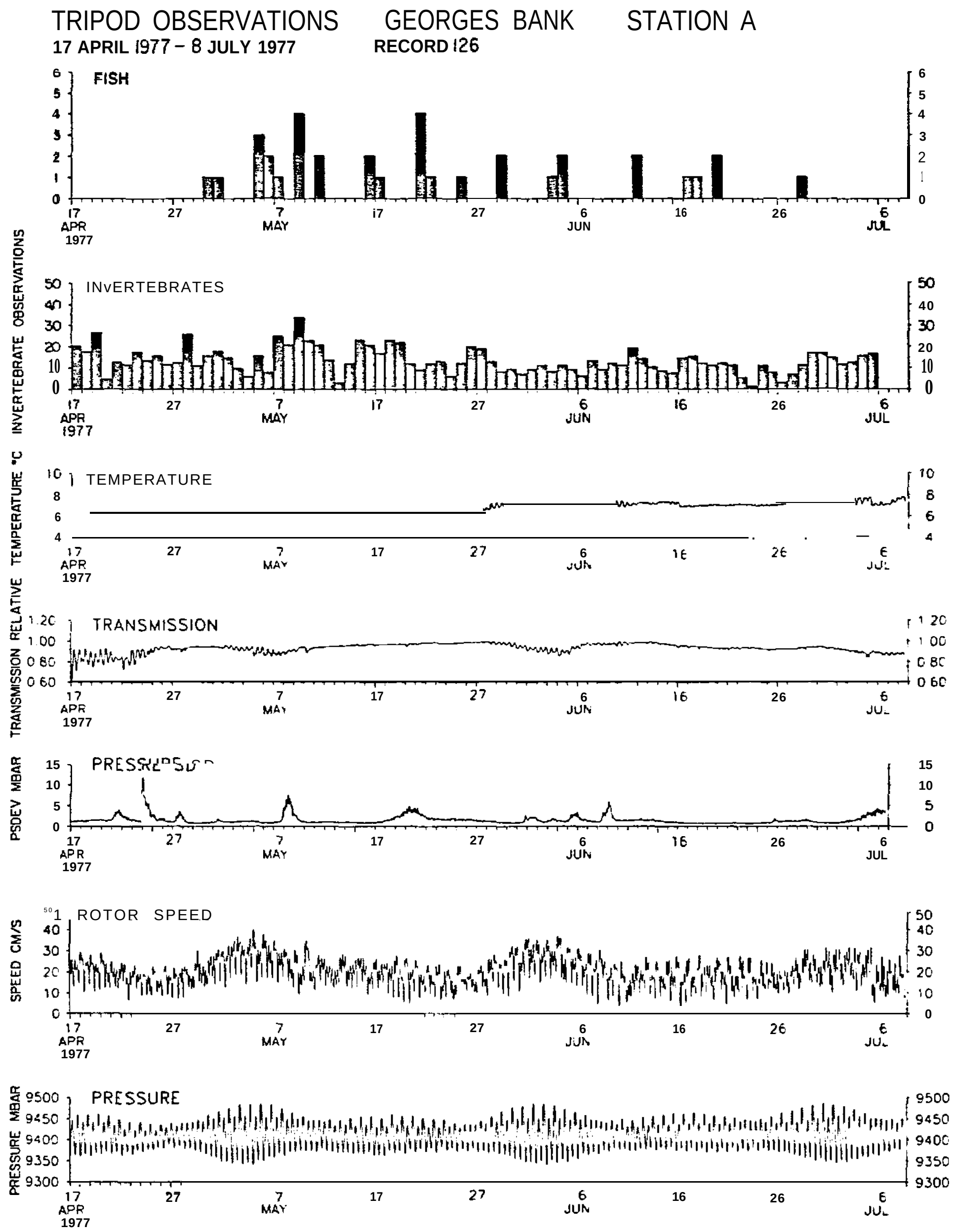

TRIPOD OBSERVATIONS GEORGES BANK STATION A
17 APRIL 1977 - 8 JULY 1977 RECORD 126
FISH
INVERTEBRATES
INVERTEBRATE OBSERVATIONS
TEMPERATURE
TEMPERATURE °C
TRANSMISSION
TRANSMISSION RELATIVE
PSDEV MBAR
ROTOR SPEED
SPEED CM/S
PRESSURE
PRESSURE MBAR
APR
1977
MAY
JUN
JUL

Figure 12. Sculpins (*Myoxocephalus*), common scavengers, observed in May.

A. One yearling and mature sculpin observed near current meter vane. A gastropod (lower left) and several browser tracks are also visible.

B. Two mature sculpin. There is more fecal matter near the paired (mollusk) and singular (worm) holes than was observed in early May.

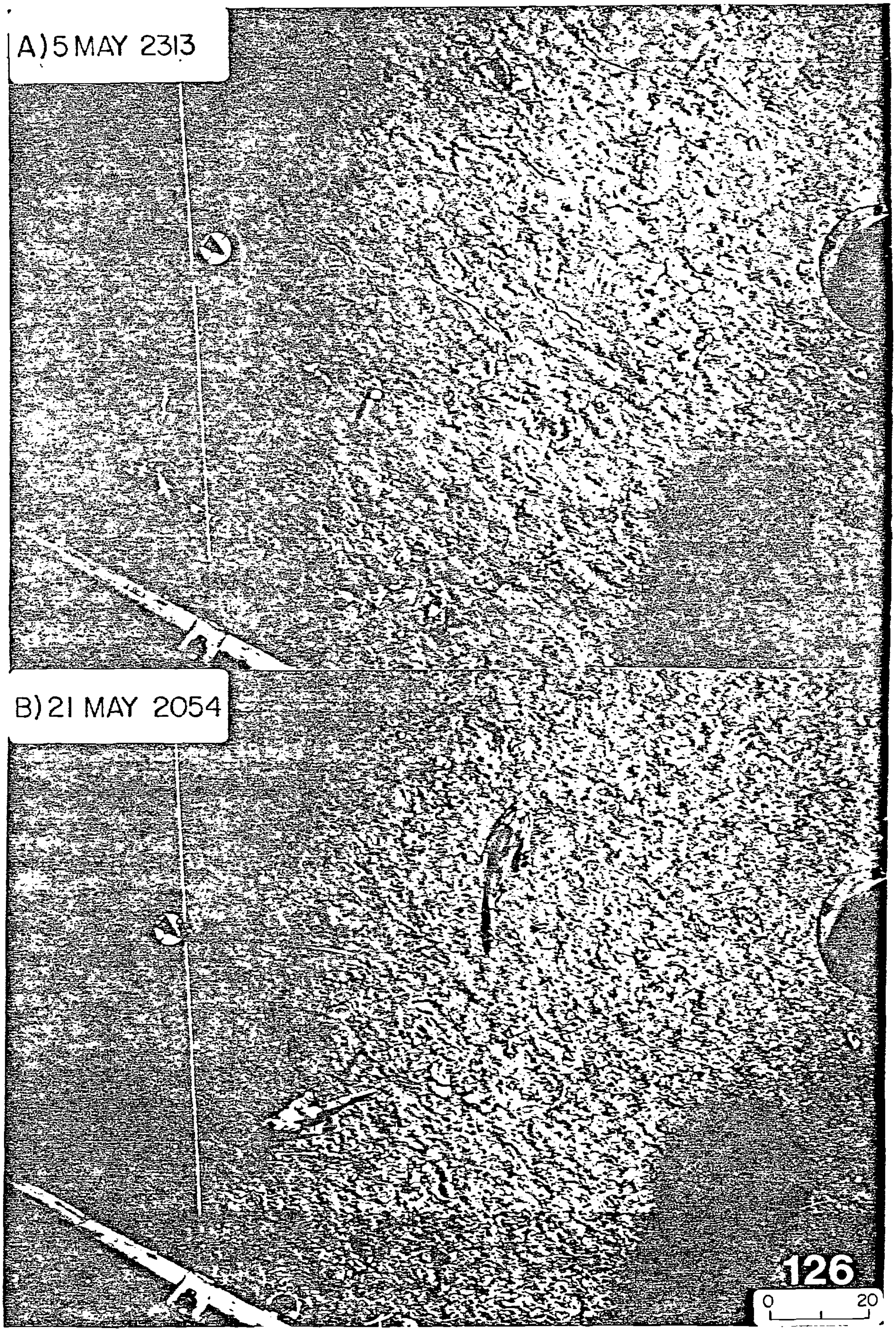

A) 5 MAY 2313
B) 21 MAY 2054
126
0
20

Figure 13. A. Pits made by a hermit crab (*Pagurus* sp.).

B. Intense pitting caused by hermit crabs scavenging the bottom.

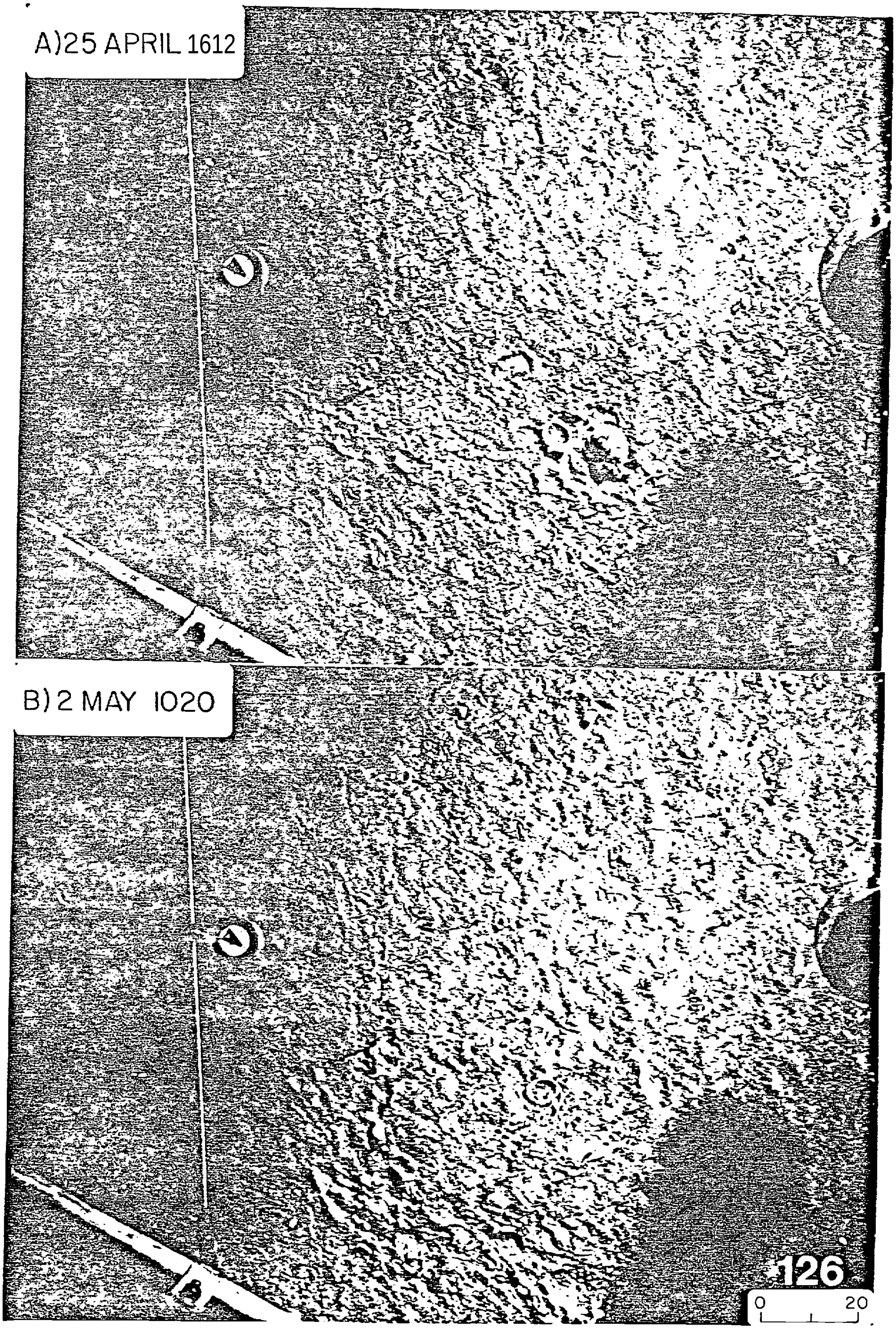

A) 25 APRIL 1612
B) 2 MAY 1020
126
0
20

Figure 14. A. Two gastropod (lower left and upper left).

B. Pits and tracks made by gastropod scavenging the bottom.

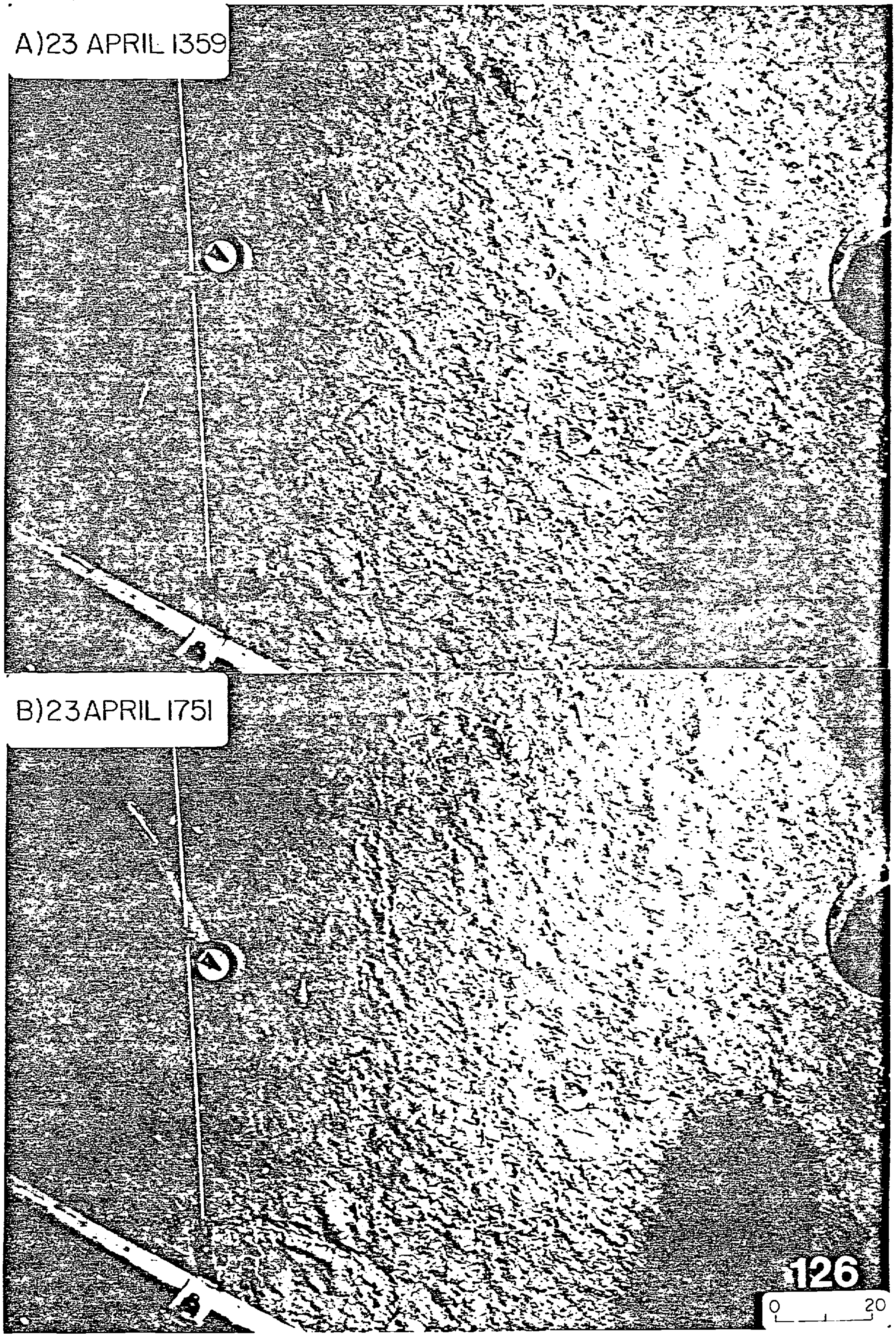

A)23 APRIL 1359
B)23 APRIL 1751
126
0
20

Figure 15. A. Carnivorous whelk (*Buccinum undatum*) in lower right burrowing in the bottom surface sediments.

B. Large pit left by same whelk in lower right.

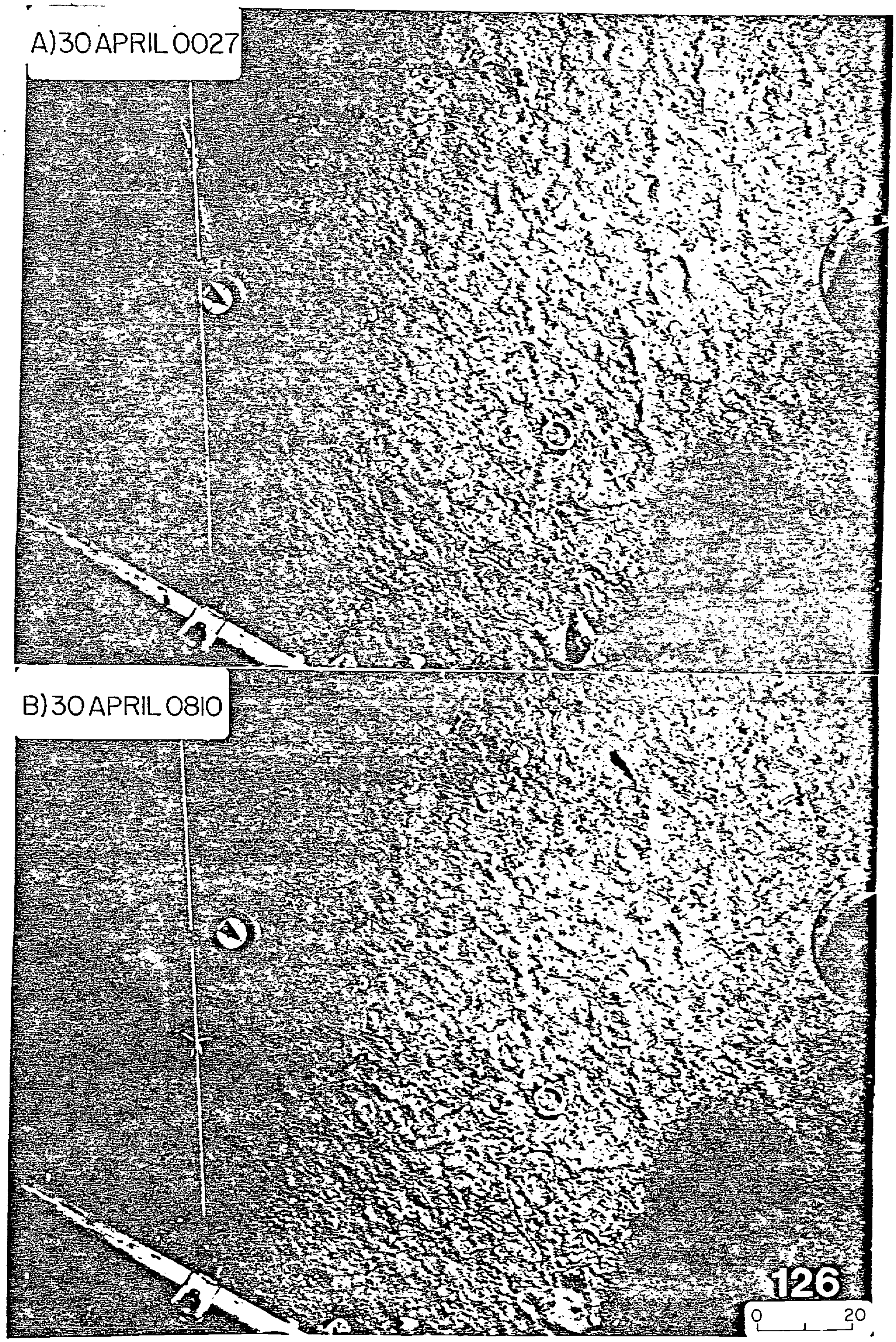

A)30 APRIL 0027
B)30 APRIL 0810
126
0
20

Figure 16. A. Moderate detrital cover prevalent in late May and June. Singular holes are probably made by polychaetes. Shadows of tubeworms are predominant in lower left. Paired siphon holes, most likely of ocean quahogs (_Arctics islandica_), are common.

B. Fecal mounds, produced largely by tubeworms and bivalve mollusks, are prevalent in July and are more compact than mounds observed in May and June.

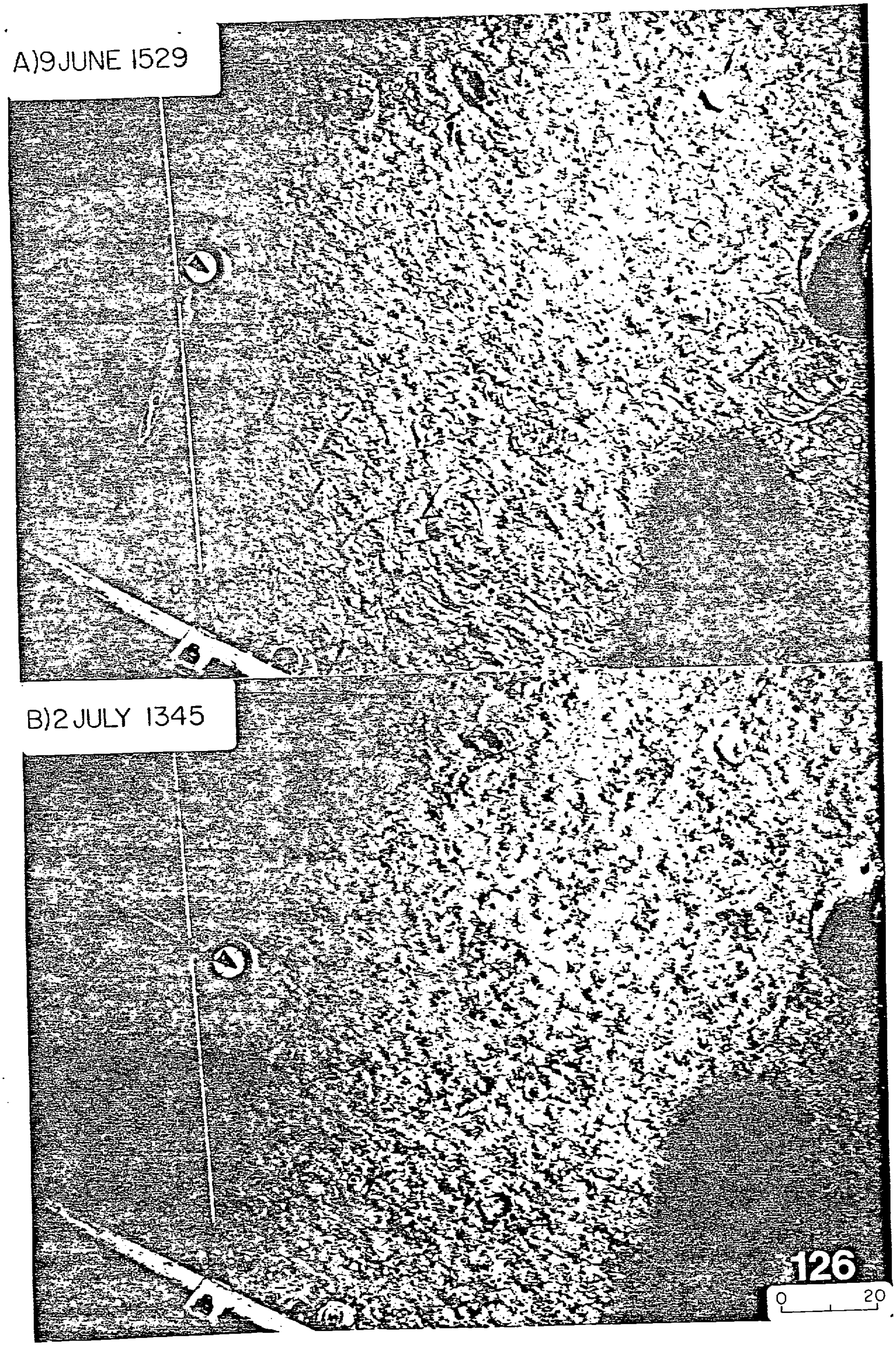

A)9 JUNE 1529
A
B
B)2 JULY 1345
A
B
126
0
20

Figure 17. Summer tripod observations from July to September 1977 (Records 128 and 132) at Station A, Georges Bank. Fish and invertebrates (mobile epibenthic) (Record 132) represent the total number observed each day from bottom photographs taken every 3 hours. Pressure standard deviation (PSDEV), current speed, and pressure (Record 132) were measured at 85-m depth. No temperature or relative light transmission data was available at 85-m depth on this deployment. The temperature was measured at 75-m depth (Record 128) and is shown with the other hour-averaged data.

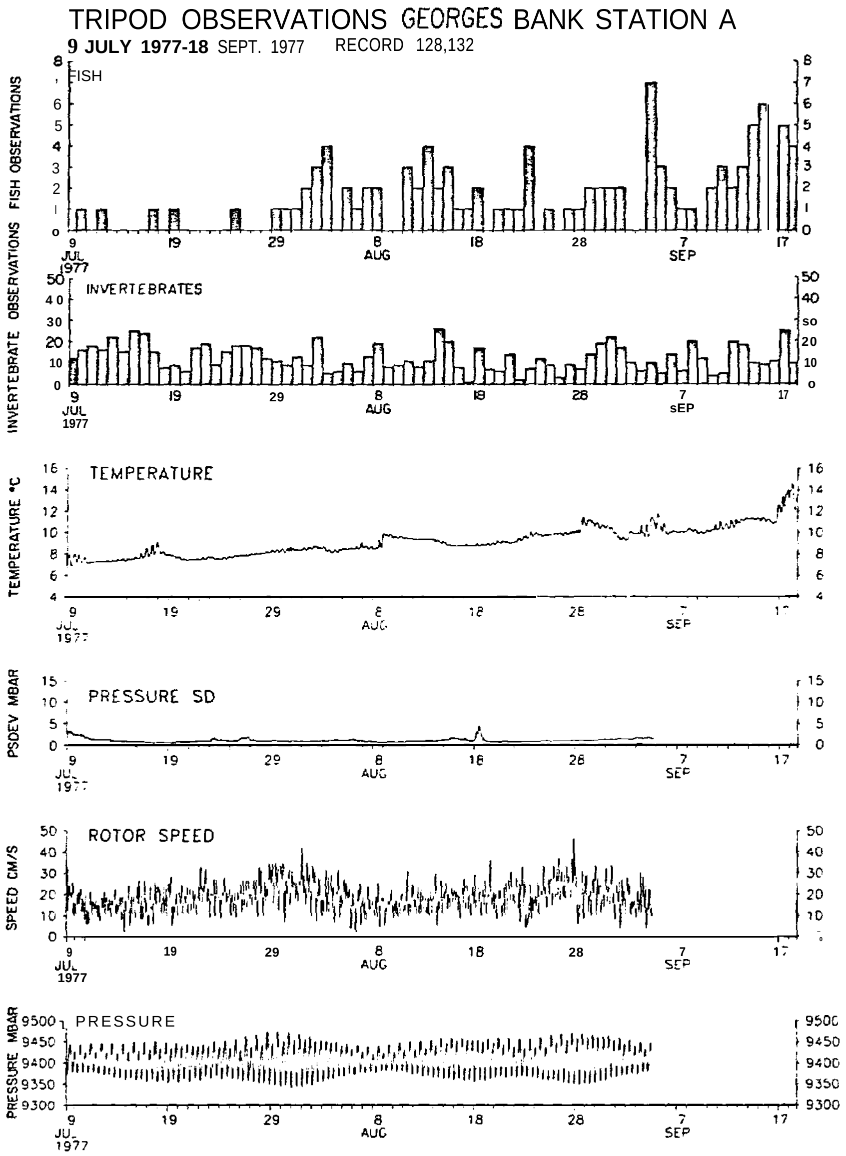

TRIPOD OBSERVATIONS GEORGES BANK STATION A
9 JULY 1977-18 SEPT. 1977 RECORD 128,132
FISH OBSERVATIONS
FISH
INVERTEBRATE OBSERVATIONS
INVERTEBRATES
TEMPERATURE °C
TEMPERATURE
PSDEV MBAR
PRESSURE SD
SPEED CM/S
ROTOR SPEED
PRESSURE MBAR
PRESSURE
9 JUL 1977
19
29
8 AUG
18
28
7 SEP
17

Figure 18. Examples of scour and resuspension during summer spring tides.

A. Resuspension and asymmetric-ripple formation.

B. Resuspension and intense tidal scour associated with bottom current speeds >40 cm/s.

C. Undisturbed bottom with conspicuous fecal mounds.

D. Resuspension, asymmetric ripples, and tidal scour. Observe reorientation of empty quahog shell from concave-up (C) to more stable convex-down (D) position as bottom current speeds increased.

Figure 18

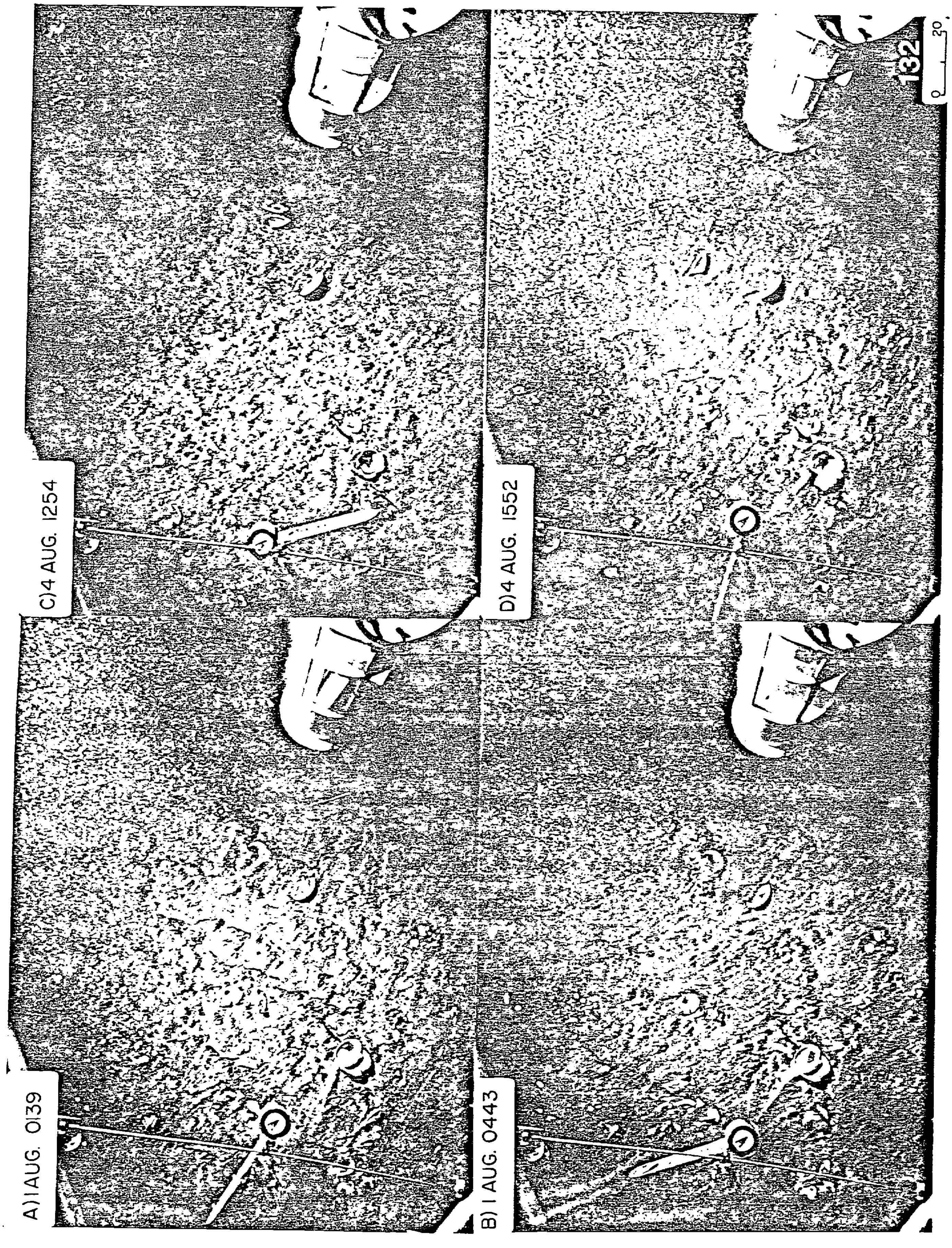


Figure 19. Predominant summer fish.

A. Hake (*Urophycis*).

B. Cod (*Gadus callarias*).

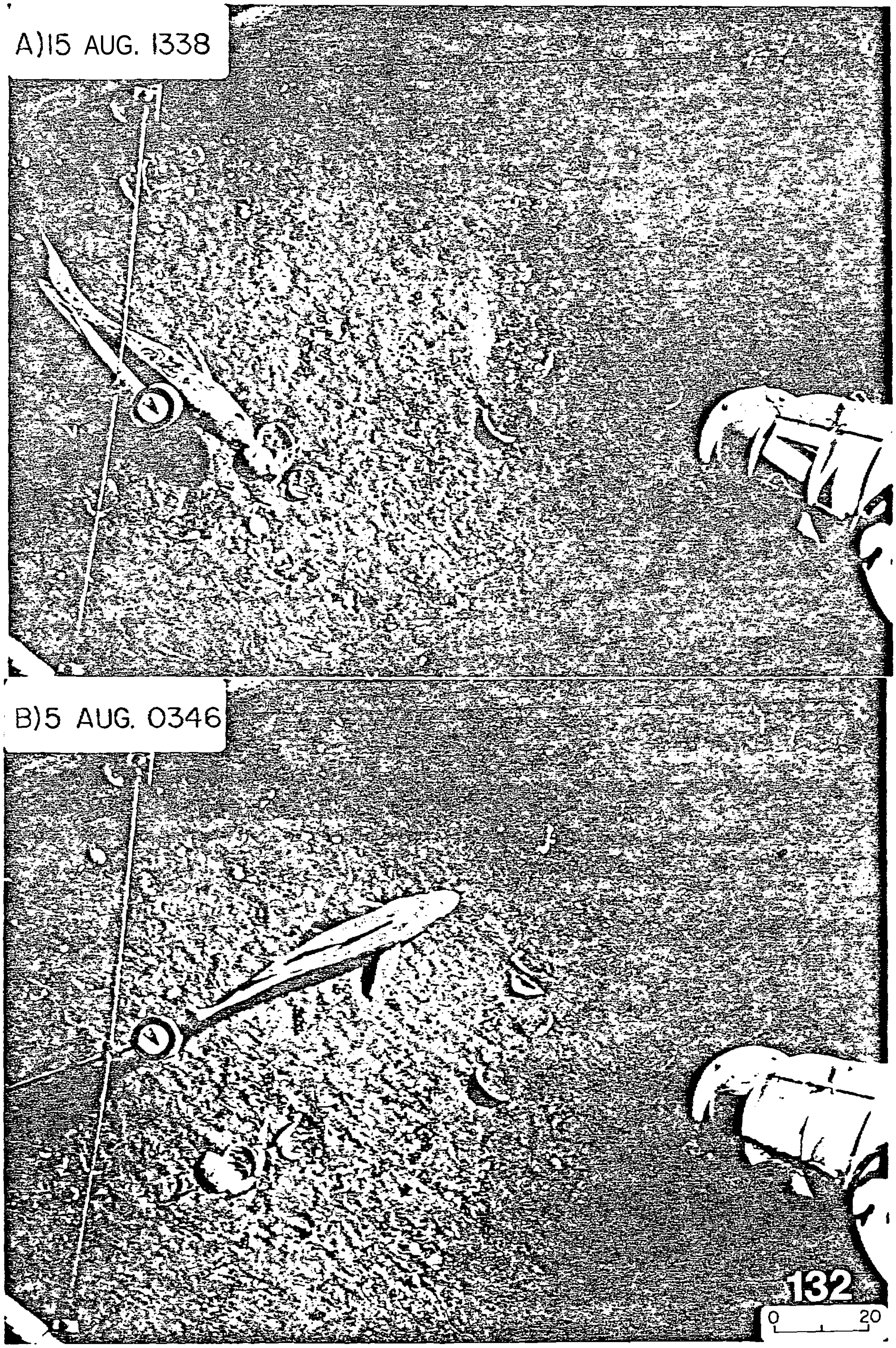

A)15 AUG. 1338
B)5 AUG. 0346
132
0
20

Figure 20. Frequently observed groundfish in July, August and September.

A. Sea raven (*Hemitripterus americanus*) and hermit crab (*Pagurus* sp.).

B. Ocean pout (*Macrozoarces americanus*).

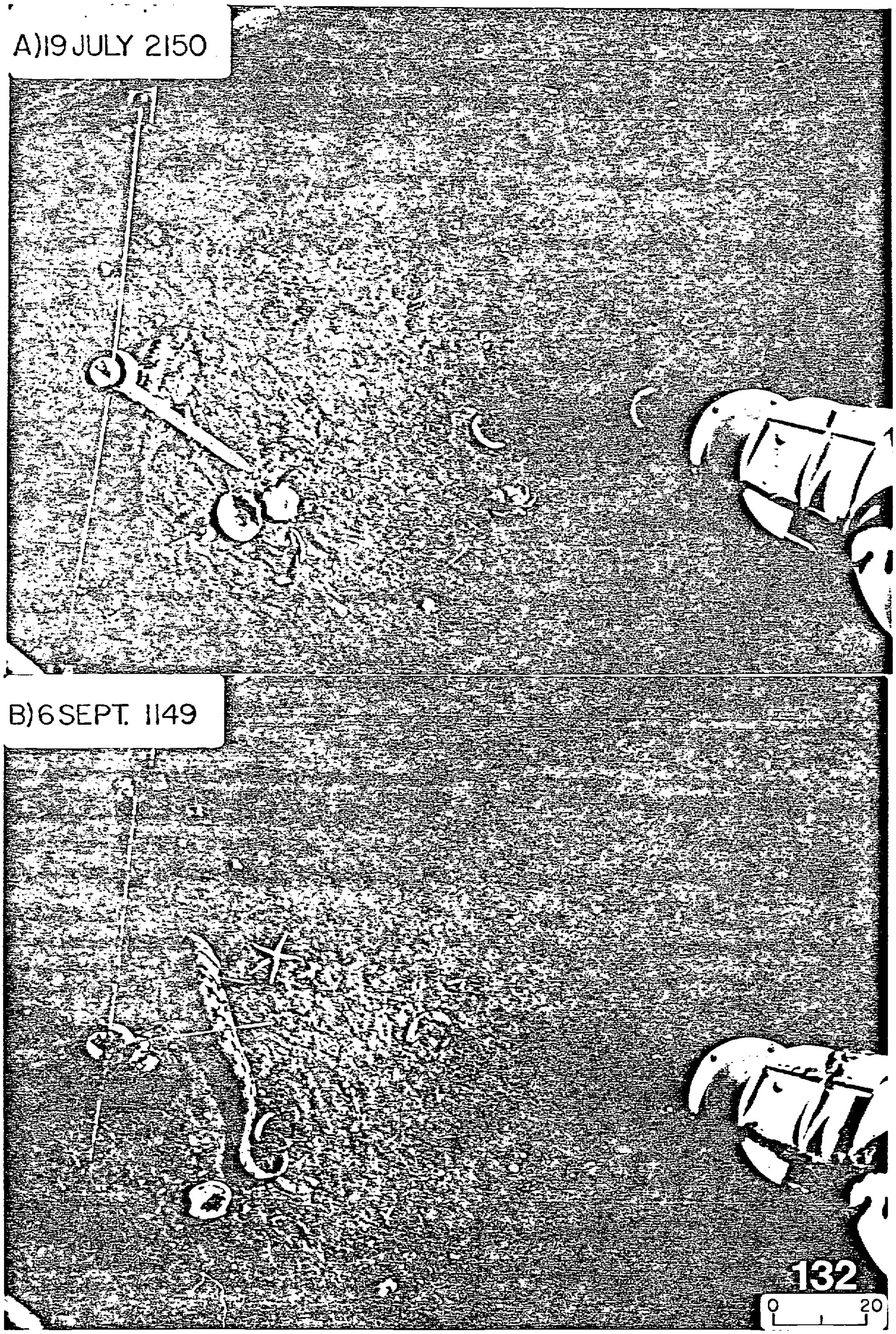

A) 19 JULY 2150
B) 6 SEPT. 1149
132
0
20

Figure 21. Common scavengers disturbing the bottom surface sediments.

A. Hermit crab (Pagurus) with its pits.

B. Jonah crabs (Cancer borealis) with their scratches.

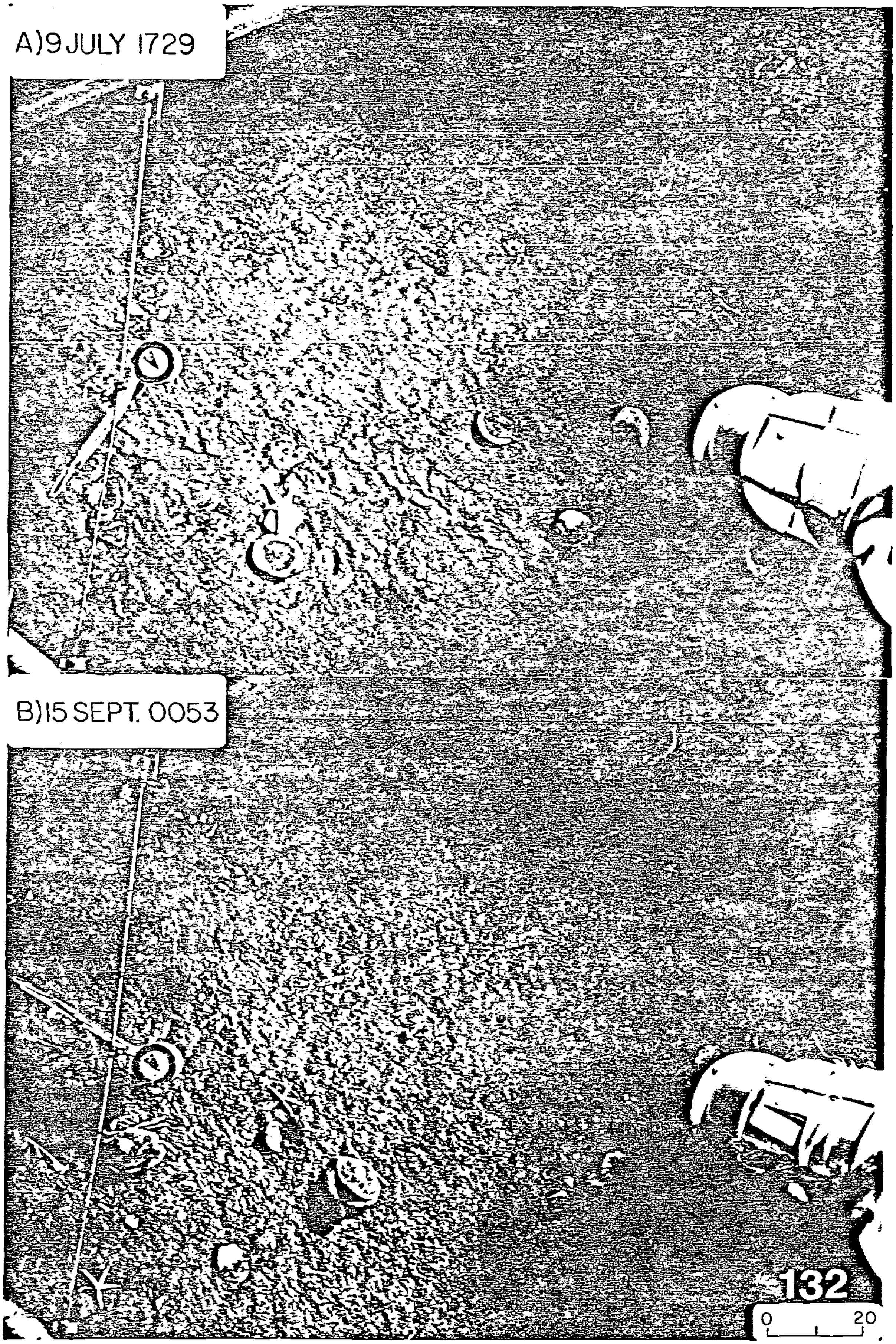

A) 9 JULY 1729
B) 15 SEPT. 0053
132
0
20

Figure 22. Moderate to extensive detrital cover predominant in August and September.

A. Cancer crab in center burrowing in surface sediments. A large hake (Urophycis), possibly 3 years old, is visible near vane.

B. Cancer crab depression-burrow is still conspicuous.

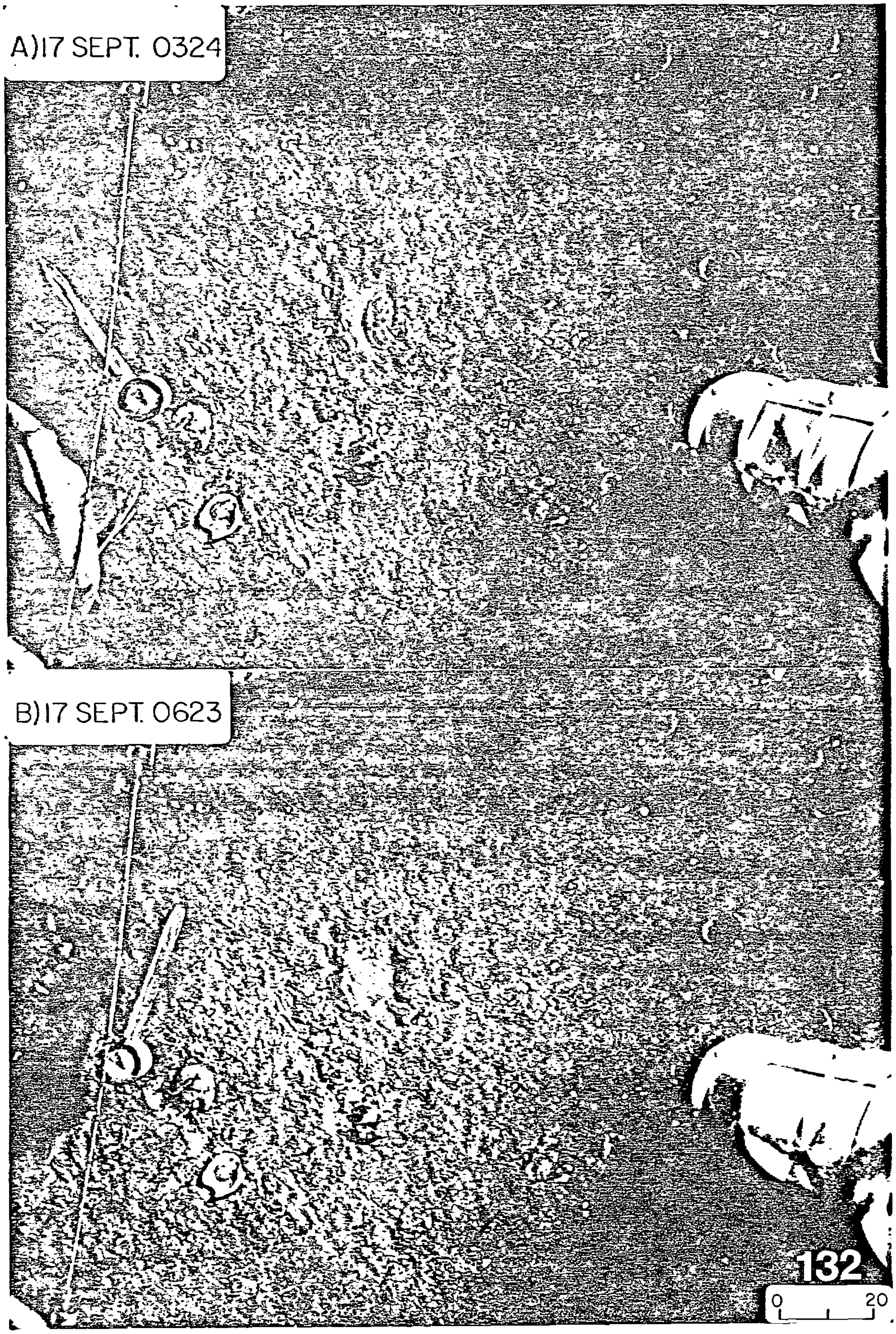

A) 17 SEPT. 0324
B) 17 SEPT. 0623
132
0
20

Figure 23. Seasonal abundance and predominance of fish and mobile epibenthic invertebrates on Georges Bank (Station A) from December 1976 to September 1977. Predominant species are designated as those fish and invertebrates photographed more than five and 25 times each per month. Photographs were taken every 4 hours from December to June and every 3 hours from July to September. The summer data is reduced by 75% so that direct comparison can be made between the three seasons. Data sets for December, March, April, July, and September were also appropriately normalized to correct for shortened observation months because of deployment and recovery operations. Mean temperatures at 85-m depth (bottom), averaged every 15 days, and at 75-m depth, averaged every 15 days and/or month are plotted to show the fish and invertebrate variability with the seasonal changes in temperature.

SEASONAL ABUNDANCE AND PREDOMINANCE OF FISH AND MOBILE BENTHIC INVERTEBRATES

GEORGES BANK STATION A DECEMBER 1976- SEPTEMBER 1977

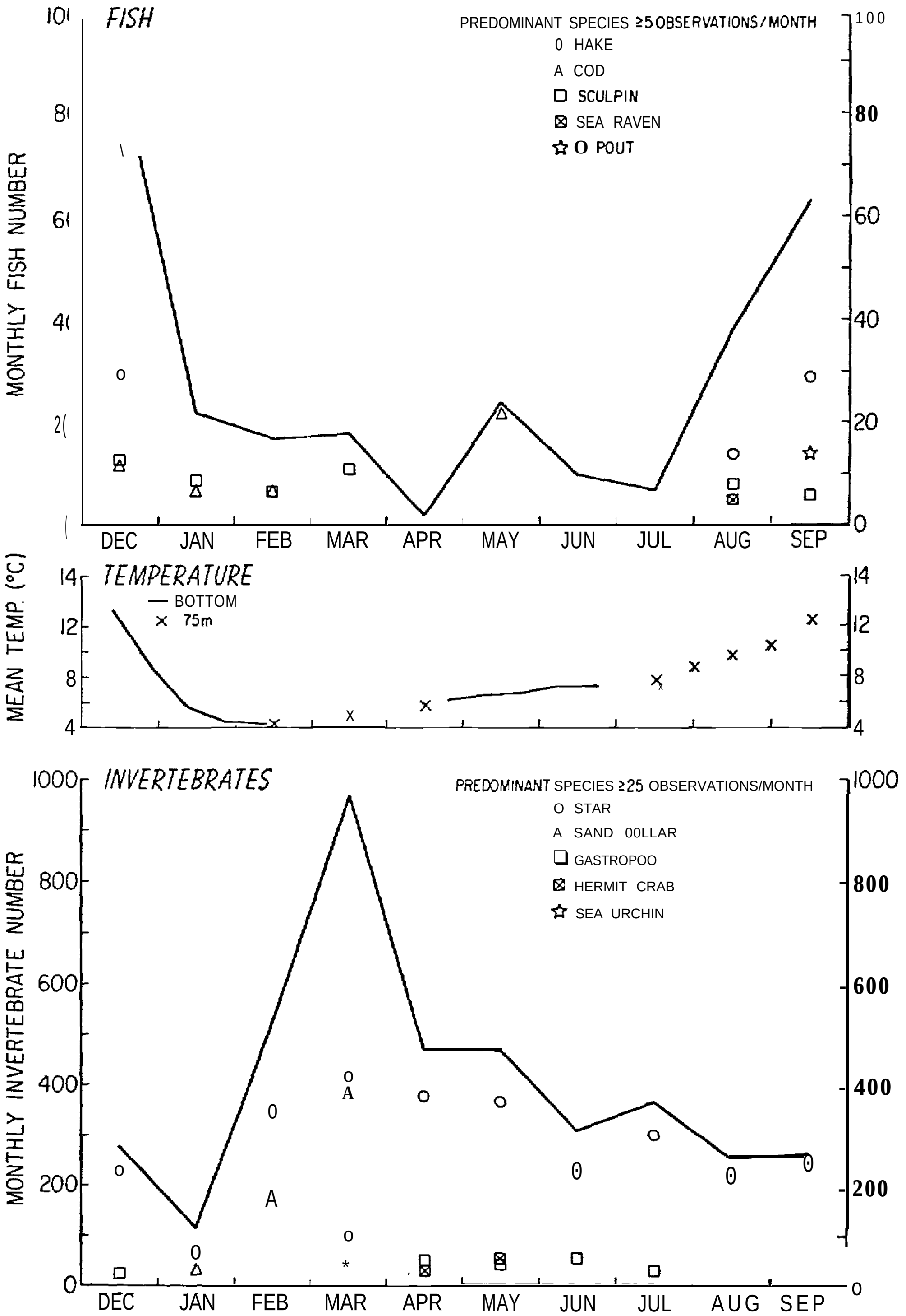


Figure 24. Monthly fish number plotted against mean temperature ($\bar{x}$) and temperature standard deviation (@ at 75-m depth. Linear regression coefficients (R) are indicated for each. Numerals adjacent to plotted points represent the calender month (i.e., January=1) in which the data was collected.

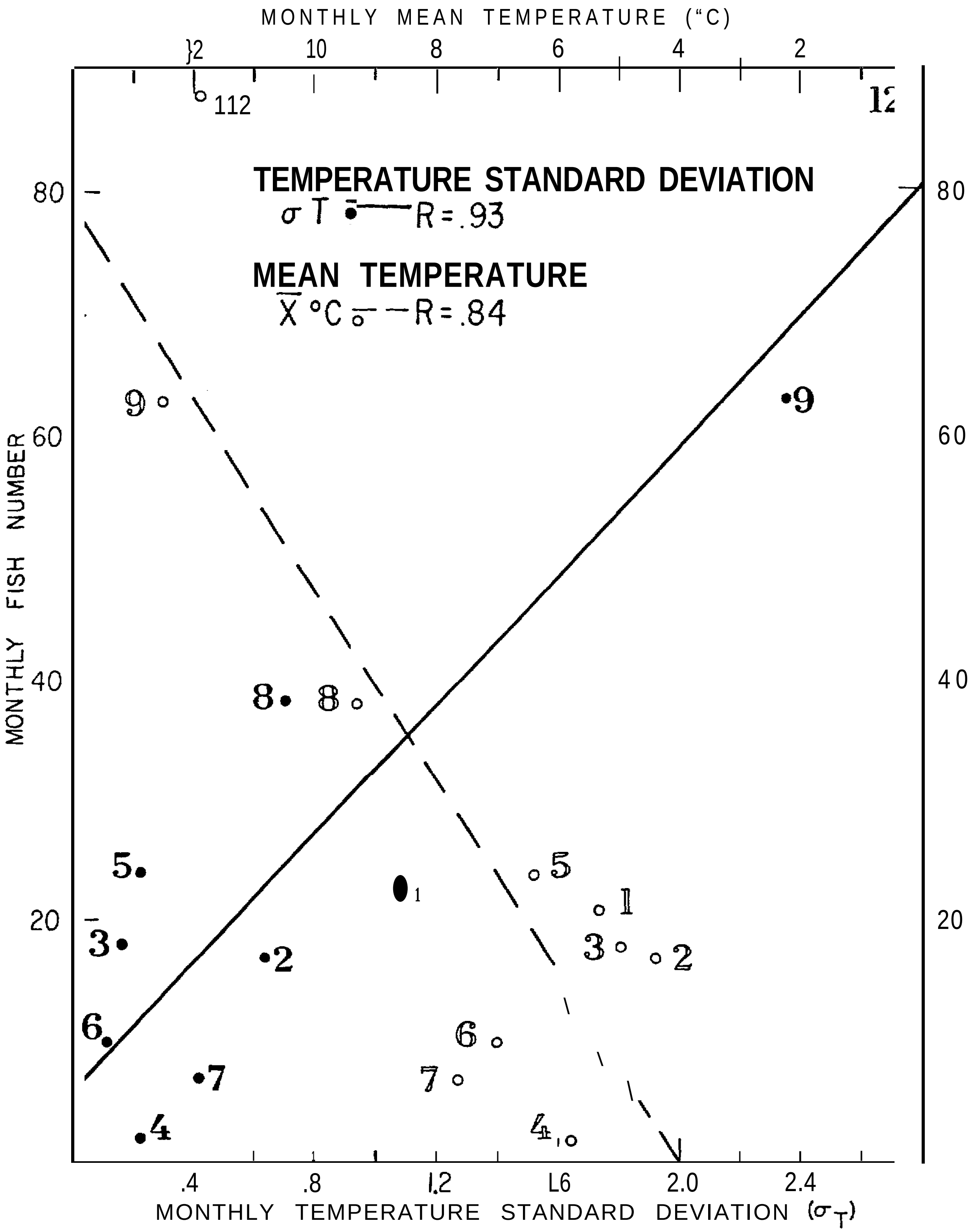

MONTHLY MEAN TEMPERATURE (°C)
12
10
8
6
4
2
112
12
TEMPERATURE STANDARD DEVIATION
σT • — R=.93
MEAN TEMPERATURE
X̄ °C ○ — R=.84
MONTHLY FISH NUMBER
80
60
40
20
.4
.8
1.2
1.6
2.0
2.4
MONTHLY TEMPERATURE STANDARD DEVIATION (σT)

Table 1. Number of fish photographed at Station A, winter 1976-77

[For each time interval, column A is the total number of fish observed and column B is the average number of fish observed per day, based on a sampling rate of 4 hours (6 pictures per day). For the monthly observations, the number in parentheses is the total extrapolated to a full month. "Other" species include all unidentified fish]

	OBSERVATIONS WITHIN SELECTED TEMPERATURE INTERVALS								MONTHLY OBSERVATIONS			
	06 December 1976- 24 December 1976		25 December 1976- 02 January 1977		03 January 1977- 04 February 1977		05 February 1977 17 March 1977		December 6-31	January 1-31	February 1-28	March 1-17
Species	A	B	A	B	A	B	A	B	A	A	A	A
Hake	24	1.26	1	.11	3	.09	0	.00	25	3	0	0
Cod	1	.05	18	2.00	1	.03	13	.32	11	9	7	6
Haddock	1	.05	1	.11	0	.00	2	.05	2	0	1	1
Pollock	3	.16	0	.00	0	.00	0	.00	3	0	0	0
Sculpin	4	.21	6	.67	8	.24	6	.15	10	7	7	0
Flounder	1	.05	0	.00	1	.03	0	.00	1	1	0	0
Goosefish	6*	.32	0	.00	0	.00	0	.00	6	0	0	0
Eel	1	.05	2	.22	0	.00	0	.00	3	0	0	0
Skate	0	.00	1	.11	0	.00	0	.00	0	1	0	0
Other	12	.63	2	.22	0	.00	5	.12	13	1	2	3
TOTAL	53**	2.79	31	3.44	13	.39	26	.63	74	22	17	10
									(88)	(22)	(17)	(18)

*Six photographs, probably all of the same individual.
**Two squid were also observed in this time period but are not included in total count.

Table 2. Number of mobile benthic invertebrates photographed at Station A, winter 1976-77

[For each time interval, column A is the total number of invertebrates observed and column B is the average number of invertebrates observed per day, based on a sampling rate of 4 hours (6 pictures per day). For the monthly observations, the number in parentheses is the total extrapolated to a full month. "Other" species include uncommon and infrequently observed species]

	OBSERVATIONS WITHIN SELECTED TEMPERATURE INTERVALS								MONTHLY OBSERVATIONS			
	06 December 1976- 24 December 1976		25 December 1976- 02 January 1977		03 January 1977- 04 February 1977		05 February 1977 17 March 1977		December 6-31	January 1-31	February 1-28	March 1-17
Species	A	B	A	B	A	B	A	B	A	A	A	A
Starfish	174	9.16	21	2.33	75	2.27	566	13.80	193	64	348	231
Gastropod	17	.89	3	.33	20	.61	64	1.56	20	20	6	58
Hermit crab	5	.26	1	.11	2	.06	11	.27	6	2	3	8
Sand dollar	8	.42	4	.44	34	1.03	374	9.12	12	29	168	211
Sea urchin	0	.00	0	.00	0	.00	21	.51	0	0	0	21
Other	0	.00	0	.00	2	.06	1	.02	0	2	0	1
TOTAL	204	10074	29	3.22	133	4.03	1037	25.29	231	117	525	530
									(275)	(117)	(525)	(964)

Table 3. Number of fish photographed at Station A, spring 1977.

[For each time interval, column A is the total number of fish observed and column B is the average number of fish observed per day, based on a sampling rate of 4 hours (6 pictures per day). The number in parentheses is the total observations extrapolated to a full month. "Other" species include all unidentified fish. Yearlings have been enumerated for major fish species]

MONTHLY OBSERVATIONS

	17-30 April 1977		1-31 May 1977		1-30 June 1977		1-5 July 1977	
Species	A	B	A	B	A	B	A	B
Flake	0	.00	0	.00	1	.03	0	.00
Yearlings	0	.00	0	.00	0	.00	0	.00
Sculpin	0	.00	10	.32	3	.10	0	.00
Yearlings	1	.07	12	.42	0	.00	0	.00
Oceanpout	0	.00	0	.00	2	.07	0	.00
Yearlings	0	.00	0	.00	1	.03	0	.00
Eel	0	.00	0	.00	2	.07	0	.00
Other	0	.00	2	.06	1	.03	0	.00
TOTAL	1	.07	24	.77	10	.33	0	.00
	(2)		(24)		(10)			

Table 4. Number of mobile benthic invertebrates photographed at Station A, spring 1977

[For each time interval, column A is the total number of invertebrates observed and column B is the average number of invertebrates observed per day, based on a sampling rate of 4 hours (6 pictures per day). The number in parentheses is the total observations extrapolated to a full month. "Other" species include uncommon and infrequently observed species]

MONTHLY OBSERVATIONS

	17-30 April 1977		1-31 May 1977		1-30 June 1977		1-5 July 1977	
Species	A	B	A	B	A	B	A	B
Starfish	179	12.78	370	11.94	229	7.63	47	9.40
Gastropod	24	1.71	42	1.35	54	1.80	11	2.20
Hermit crab	15	1.07	52	1.71	23	.77	2	.40
Cancer crab	0	.00	1	.03	4	.13	12*	2.40
Other crabs	4	.29	7	.23	0	.00	0	.00
Others	1	.07	2	.06	3	.10	1	.20
TOTAL	223	15.93	474	15.29	313	10.43	73	14.60
	(474)		(474)		(313)			

*Twelve photographs, probably all of the same individual.

Table 5. Number of fish photographed at Station A, summer 1977

[For each time interval, column A is the total number of fish observed and column B is the average number of fish observed per day, based on a sampling rate of 3 hours (8 pictures per day). For the monthly observations, the number in parentheses is the total extrapolated to a full month, then reduced by 0.75 to correct for the faster sampling rate so that direct comparisons with Tables 1 and 3 can be made. "Other species include all unidentified fish]

	OBSERVATIONS WITHIN SELECTED TEMPERATURE INTERVALS										MONTHLY OBSERVATIONS		
	09 July 1977-07 August 1977		08 August 1977-27 August 1977		28 August 1977-02 September 1977		03 September 1977-15 September 1977		16 September 1977-18 September 1977		July 9-31	August 1-31	September 1-18
Species	A	B	A	B	A	B	A	B	A	B	A	A	A
Hake	10	.33	9	.45	3	.50	15	1.15	8	2.67	3	19	23
Cod	7	.23	4	.20	1	.17	3	.23	1	.33	1	10	5
Sculpin	2	.07	3	.15	0	.00	1	.08	0	.00	2	3	1
Sea raven	1	.03	2	.10	4	.67	1	.08	0	.00	1	6	1
Oceanpout	0	.00	1	.05	0	.00	7	.54	4	1.33	0	1	11
Eel	0	.00	2	.Lo	0	.00	0	.00	0	.00	0	2	0
Goosefish	0	.00	o	.00	1	.17	0	.00	0	.00	0	0	1
Other	2	.07	8	.40	0	.00	8	.62	0	.00	1	9	8
TOTAL	22	.73	29	1.45	9	1.50	35	2.69	13	4.33	8	50	50
											(7)*	(38)	(63)

*Extrapolation for July includes data from Table 3.

Table 6. Number of mobile benthic invertebrates photographed at Station A, summer 1977

[For each time interval, column A is the total number of invertebrate Observed and column B is the average number of invertebrates observed per day, based on a sampling rate of 3 hours (8 pictures per day). For the monthly observations, the number In parentheses is the total extrapolated to a full month, then reduced by 0.75 to correct for the faster sampling rate so that direct comparisons with Tables 2 and 4 can be made. "Other" species include uncommon and infrequently observed species]

	OBSERVATIONS VIA TEMPERATURE INTERVALS										MONTHLY OBSERVATIONS		
	09 July 1977- 07 August 1977		08 August 1977 27 August 1977		28 August 1977- 02 September 1977		03 September 1977- 15 September 1977		16 September 1977- 18 September 1977		July 9-31	August 1-31	September 1-18
Species	A	B	A	B	A	B	A	B	A	B	A	A	A
Starfish	365	12.17	172	8.60	79	13.17	128	9.85	43	14.33	301	291	195
Gastropod	23	.77	15	.75	6	1.00	7	.54	0	.00	20	22	9
Hermit crab	20	.67	9	.45	3	.50	4	.31	2	.67	16	15	7
Cancer crab	4	.13	10	.50	0	.00	0	.00	1	.33	4	10	1
Other crabs	3	.10	0	.00	1	.17	0	.00	0	.00	3	1	0
Othera	1	.03	2	.10	0	.00	0	.00	0	.00	1	2	0
TOTAL	416	13.87	208	10.40	89	14.83	139	10.69	46	15.33	345	341	212
											(369)*	(256)	(265)

*Extrapolate ion for July includes data from Table 4.